Composites Science and Technology 168 (2018) 188–194

Contents lists available at ScienceDirect

Composites Science and Technology

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

A methodology for modeling the relationship between process and topological yarn structure of 3D rotary braided rectangular preforms

Haiyang Mei, Zhenyu Han, Guangyu Lu, Hongyu Jin*

School of Mechatronic Engineering, Harbin Institute of Technology, Harbin, 150001, China

ARTICLE INFO

Keywords:
A.Textiles
C.Modeling
E.Braiding

ABSTRACT

3D braided composites have been widely used in high-performance fields due to their excellent properties closely related to the special yarn structures. However, the capability to fabricate various yarn structures with flexible 3D rotary braiding method has not been systematically investigated. This paper proposes a methodology to model the process/topological yarn structure relationship of 3D rotary braided rectangular preforms. A novel algorithm is developed to trace the carrier path with machine control code, in which the carrier motion is expressed as mathematical functions of switch rotation status. Without considering yarns' volume, the lattice-like ideal yarn topology is established using the yarn trajectories. To construct the real yarn topology, yarn topologies at the nodes which depend on corresponding switch rotation direction are studied. The yarn structure is explored within a representative unit owing to its repetitiveness, and specific switch rotation direction combinations which allow yarns to maintain straight in the preforms are derived.

1. Introduction

3D braided composites have attracted extensive attention due to their excellent mechanical properties, such as better out-of-plane properties, high damage tolerance, and excellent fatigue characteristics. As one kind of fiber reinforced composites, these properties stem from their specific yarn structures. Several 3D braiding methods are commonly used such as four-step braiding, two-step braiding, interlock layer-to-layer braiding and rotary braiding. In order to design braided preforms, many works were carried out on the process and microstructure of them in the past.

Four-step braiding is the most widely used among these methods, and studies were mainly focused on it too. Ko [1]first identified a unit cell representing the fiber architecture in rectangular braided preforms, which was a cuboid containing four diagonally intersecting yarns. Li et al. [2] reported an idealized model which represented the real yarn direction and interlacing status based on the cross-section cut longitudinally at 45° angle with the preform surface. Wang and Wang [3] presented a tool called control volume method to analyze the yarn structure topology based on the braiding procedure, and several substructures were identified. Chen et al. [4] established three types of unit cell models on the basis of microscopic observation, and mathematical relationships among structural parameters were derived. Zhang et al. [5] built the model of unique yarn structure in the joint region in complex rectangular preforms. Zhang et al. [6] developed a software which can automatically produce geometric models of 3D braided preforms with different parameters. Wang et al. [7,8] developed the multi-chain digital element method to simulate the braiding process and fabric deformation. Wang et al. [9] proposed an efficient method called preform boundary reflection to simplify the modeling process. Ma et al. [10] represented an algorithm to simulate the four-step braiding process based on matrix theory and symbol operation. These works show that the yarn structure of four-step braided rectangular preforms has been fully investigated and it mainly depends on the carrier configuration due to the bald four-step braiding process. Now researches are focused on the simulation of yarn deformation [11,12] and numerical analyses on mechanical behavior [13,14].

Besides, various 3D rotary braiding methods [15–17] have been developed, which have much flexible carrier paths than four-step braiding. The ratio of carriers' amount to horn-gears' doubled when the switch mechanism in lace braider is adopted [18]. When the carrier arrangement is irregular or not all yarns pass through the whole thickness, it is ineffective to use the process/yarn structure models from four-step braiding. And, textiles with complex yarn structures have become more important than ever before as the preform of composites components [19,20]. Makiko et al. [21] represented an approach to translate the 3D braided structures into a rotary machine braiding procedure from the aspect of braiding pattern. Tolosana et al. [22] proposed a model which consists of logical operation and curve fitting to emulate the operation of a typical rotary braiding machine in order

---

* Corresponding author.
E-mail address: jinhy@hit.edu.cn (H. Jin).

https://doi.org/10.1016/j.compscitech.2018.09.022
Received 3 April 2018; Received in revised form 23 August 2018; Accepted 27 September 2018

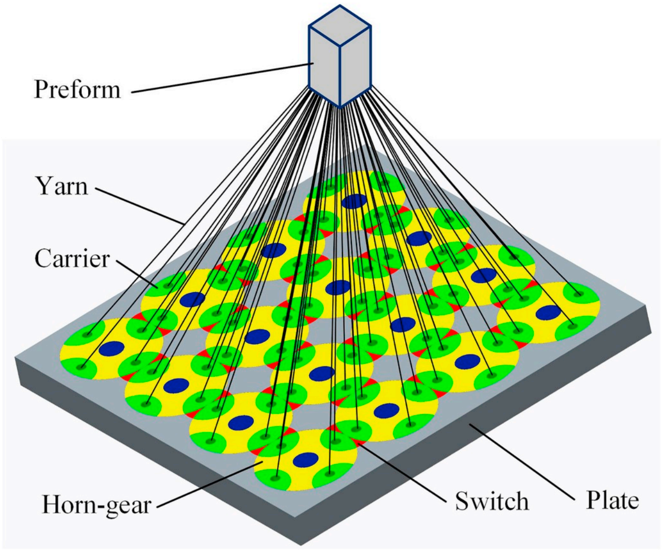


Fig. 1. Scheme of 3D rotary braider.

to automatically obtain the braided structure. These studies provided us multiple perspectives to understand the 3D rotary braiding process, but it is difficult to apply them to automated design and manufacturing of 3D rotary braided preforms.

The aim of this paper is to model the relationship between process and topological yarn structure of 3D rotary braided rectangular preforms. Contributions are summarized as follows. An novel algorithm is developed which makes carrier paths computable. The similarity between the ideal yarn topology and lattice structure is found. The switch rotation direction's effect on yarn structures is concluded, and optimal switch rotation direction combinations are derived.

The rest of this paper is organized as follows. Section 2 introduces the typical 3D rotary braiding process. Section 3 illustrates the algorithm for modeling braiding process. Section 4 demonstrates the analytical procedure on yarn structures. Conclusions are summarized in Section 5.

2. The 3D rotary braiding process

The scheme of 3D rotary braider which is studied in this paper is shown in Fig. 1. Horn-gears are assembled on the plate in configuration of rows and columns, and adjacent horn-gears have opposite rotation directions. Each horn-gear consists of four slots, which means it can hold up to four carriers simultaneously. Between two adjacent horn-gears is the switch, a special device which is controlled individually to allow or prevent from the interchange of two adjacent carriers.

The mechanism of carrier motion includes two parts: rotation around horn-gears and rotation around switches, which is shown in Fig. 2. After 90° rotation of horn-gears, switches rotate half a circle in order to exchange the position of adjacent carriers, which leads to yarn interlacing. When the horn-gear rotation direction is definite, multiple carrier paths would be obtained by controlling switches' rotation. Though this mechanism is easy to be described in logical programming language when carriers are described as accessories of horn-gears, it is hard to be presented as computable mathematical expressions.

3. Algorithm for modeling 3D rotary braiding process

3.1. Basic concept

Since horn-gears' rotation status keeps unchanged in the braiding process, the carrier path depends on the switch rotation status. Hence, a new perspective is taken to model the carrier configuration which is irrelative to horn-gears. As shown in Fig. 3, the initial carrier arrangement is exhibited in configuration of rows and columns by rotating horn-gears back 45° respectively. In this case, a braiding cycle is characterized by 90° rotation of horn-gears, for the carrier configurations are the same before and after a braiding cycle. Carrier motion trends in the braiding cycle are derived based on their relative position to the horn-gears these carriers follow and the horn-gear rotation direction, as shown in Fig. 3(b). For instance, carrier ”12” has the trend to move rightward and downward.

After a braiding cycle, the position of each carrier will change. The effect of switch rotation status on carrier motion is shown in Fig. 4. If the switch rotates in this braiding cycle, carrier ”12” would go downward one step and rightward one step, as shown in Fig. 4(a). On the opposite, if the switch does not rotate, carrier ”12” has no access to move rightward and can only go downward one step, as shown in Fig. 4(b).

The switch's function is inferred as a ”door”. As shown in Fig. 5, when the door is open, carriers which tend to get through the door will pass, such as carriers ”12”, ”13”, ”22”, ”32”. When the door is locked, carrier motions towards corresponding directions are restricted, such as other carriers. According to the definition above, the border of the plate is considered as a combination of locked doors. Also, it is concluded

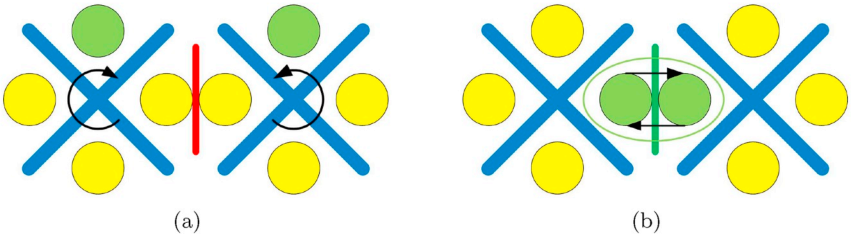
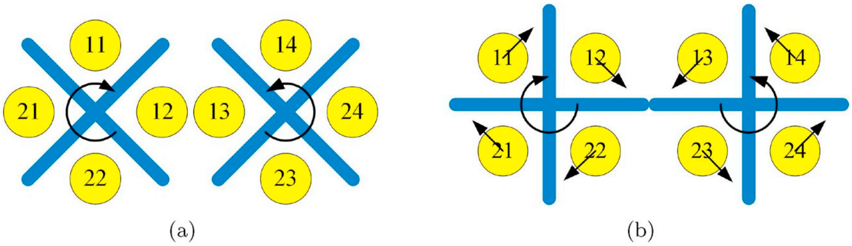

(a) (b)

Fig. 2. Mechanism of carrier motion. (a) Rotation around horn-gears; (b) Rotation around switches.



(a) (b)

Fig. 3. Carrier arrangement. (a) Carrier arrangement before 45° horn-gear rotation; (b) Carrier arrangement after 45° horn-gear rotation.