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Computer-aided modeling of braided structures overbraiding non-cylindrical prisms based on surface transformation

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ABSTRACT

This paper presents the geometrical modeling methods for braided structures overbraiding non-cylindrical prisms. This modeling method comes from the motion analysis of braiding process. The motion of strands in braiding process could be decomposed into circumferential motion, radial motion and axial motion based on the movements of carriers and take-up roller. These motions could be re-composed to form two independent surfaces: the braiding surface and helical surface, which include all information of strand movements in braiding process. Therefore, the strands could be obtained by the intersections of these two surfaces. The helical surfaces define the position of strands and the pitch while the braiding surfaces define the interlacing patterns and the outline of braids. For different braids overbraiding complicated structures, the simulated braids could be obtained by changing the braiding surfaces. Based on this theory, this paper illustrated the modeling methods for braids overbraiding prisms, which generated by extruding, sweeping, revolving and lofting respectively.

1. Introduction

Braiding is a traditional technique normally employed for producing rope-like structures. From old natural fiber ropes to modern high-performance ropes, the braiding has extensive influences on our industries. With the development of composites, it has been extended its horizons to develop 3D complex performs that can be used in advanced fiber-reinforced composites by overbraiding a complicated mandrels, as shown in Fig. 1. These complicated structures include not only the common structures like some revolting structures in Fig. 1(a) but also tubular composites in Fig. 1(b) and their combined structures in Fig. 1(c). These structures with special outlines are widely used and play important roles in aerospace and automobile industries due to their number of advantages including the high strength-to-weight ratio and the flexibility to the complicated shapes [1–3].

The complicated outlines and the existence of strand crimps increase the complexity and difficulty for the analytical and geometrical modeling. Up to now, most of relevant research works focused on the discussions about the relationships among structural parameters and the corresponding performances based on the experiments. As to the geometrical modeling, some scholars [4,5] presented the modeling methods for cylindrical structures with different braiding patterns based on different theories, while for non-cylindrical braids, there are few scholars involved in this field.

Computer-aided design together with the finite element method create powerful sophisticated tools for the modeling and analysis of complicated braids and make it possible to analyze the interactions and the distribution of stress and displacement and this analytical method has become the effective method for engineering researches. For this analytical method, the premise and base is the precise and accurate geometrical models.

This paper aims at the geometrical modeling of complicated braided structures, which could be generated by extruding, sweeping, revolving and lofting. The modeling method introduced in this paper is based on the intersection of braiding surface and helical surface using SolidWorks® as the tool. This modeling method is derived from the motions analysis of the braiding process. Therefore, in this paper, the motions of braiding process are discussed at first and two kinds of surfaces are obtained based on the decomposition and re-composition of the sub-motions. Then, the modeling method based on the intersection of surfaces is given for geometrical modeling of complicated braided structures. Based on this, the braided structures overbraiding prisms generated by extruding, sweeping, revolving and lofting are introduced respectively in details.

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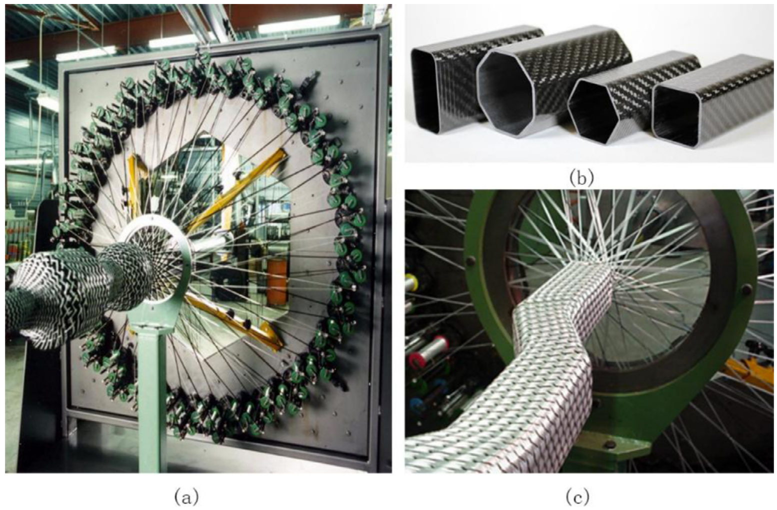

Fig. 1. Manufacture and products of non-cylindrical braids.

2. Literature review

2.1. Structural analysis of braided structures

The relevant research works on the mathematical modeling started in the 1950's, the initial research works analyzed the braided structures without considering the crimp. Brunnschweiler [6] was one of the first researchers to report on the mechanics of braid structures. He used idealized geometry to examine braiding angle and fiber coverage and developed a single equation incorporating the braiding angle θ, pitch parameter P, number of carriers N, widths of braiding and axial tows. Du and KO [7] developed geometric models for 3D braids using a unit cell approach. Du and Popper [8] developed a detailed model of the complex braiding process by over braiding a contoured mandrel. Zhang et al. [9] analyzed Two-dimensional-braid geometry and gave the results that cover factor depends braid angle, helical length, and braid diameter. Rawal [10,11] discussed the equations of yarn paths mapping on different structures including circular cylinder, circular cone, elliptical cone, square prism etc without considering the crimp structures.

With the deepening of the research, the crimp of braid was considered by researchers, Carey et al. [12] considered a sinusoidal trajectory to give a 2D configuration for only the undulation of the braiding yarns. Hristrov. et al. [13] studied the mechanical behavior of hybrid circular braids without a core under tensile loads and developed a predictive model of the mechanical response of the braids based on the constituent yarn characteristics and machine parameters. Lomov et al. [14,15] studied flat braids and proposed a geometrical model by giving the paths of the yarn centerlines within a predetermined unit cell. Alpyildiz [4] gave a kind of descriptive equation of braiding strands based on a series of assumptions, the theoretical models included the diamond braid, regular braid and Hercules braid. For the diamond braid, the crimp was treated as a sine curve. While for the other two kinds of structures, the equation of strand was described as a kind of piecewise function. This mehod is intuitive and useful for geometrical modeling. Based on Alpyildiz's mathematical models, Rawal [16] improved his previous work [11] by introducing the crimp structures and presented the mathematical models of yarns mapped on revolving bodies. Besides Alpyildiz's mathematical model, some researchers used differential geometrical methods to describe the strand curve and gave a total equation of braiding strands. Liao [17] presented a general mathematical method for braiding curve and built the real braided structures, while in their paper, the specific equations were not given. Wu [18] gave the mathematician models based on the discussion on the double braiding structures. Vu [19] presented a different modeling method. In their work, yarn of the rope is represented by a finite strain beam model. Among all these mathematical models, Alpyildiz's mathematical model was widely used to characterize many kinds of braided structures, while it is a kind of descriptive models. The Liao's and Wu's model are a kind of total description of the braiding strands. Both of them could reflect the spatial features of braiding strands.

2.2. Computer-aided modeling of braided structures

The research works on the modeling methods of braided structures are simultaneous with the mathematical modeling. At early days, the crimp was also neglected when building the braiding models, especially for the complicated structures. Brunnschweiler [6] and Zhang [20] used basic unit to describe the braided structures and discussed the relationship between geometrical parameters and mechanical properties. As the development of computer aided design techniques, it become possible to build CAD models based on mathematical equations. Adanur [21] presented three-dimensional models of fabric reinforcements for composite components by using computer aided geometric design techniques, the structures included woven fabrics, braided fabrics and knitting fabrics. Two years later, Liao and Adanur [17] fouced on the geometrical modeling of braided structures and built a series of braided models of revolting bodies. The methods of this modeling were based on their mathematical equations. Alpyildiz [4] also introduced a models method of different tubular braided structure based on his mathematical equations. Rawal [16] extended Alpyildiz's models to net-shaped braids of the revolting bodies. Both of Alpyildiz and Rawal visualized their models by using Virtual Reality Modeling Language. Recently, Kyosev [22], based on Alpyildiz's mathematical models, developed an independent computer aided braid software named TexMind braider®. For all these researches, only Liao and Rawal discussed the geometrical modeling of complicated structures, while both of them mainly focused of the revolting structures which relatively easy for mathematical expressions and up to now no relevant literatures once concern the geometrical modeling of braided structures overbraiding prism generated by extruding, sweeping, revolving and lofting. Due to the increasing application of braids with non-cylindrical structures in aerospace and automotive industries, this paper presents a general modeling