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A general approach to fast prototype the topology of braided structures

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ABSTRACT

The braiding technique has been adapted to fabricate advanced composite structures. One of the most important advantages of braiding technique is that it can form a continuous and integrated part on complex shapes which is highly challenging by other composite manufacturing methods. However, the design and analysis methodologies of braided composites such as finite element analysis are limited even with computer aided tools due to the complexity of the realistic 3D representations of braided structures. The general strategy is to use multi-scale models to account for elastic constants at each hierarchy where material properties are homogenized. If one could directly use the topology of the braided structure in the finite element analysis, there is no need to perform multi-scale analysis on the part. In this paper, we propose a general method to generate 3D representations of braided structures using explicitly expressed formulas. Kinematics of braiding, discretization of an arbitrary centerline curve, and definition of convex cross-sections along the braiding directions are the foundations required to derive the 3D geometrical representation of a braided structure on complex shape mandrel presented in the proposed method. The topology of braided structure generated by the model is validated by the physical structures which are digitized into STL file by 3D laser scanning. A finite element model based on the topology is also performed to demonstrate the robustness of the model. The model is a computationally inexpensive and versatile applicable for any non-straight and non-concave shape mandrel given that it is braidable.

1. Introduction

The braiding technique has existed since ancient times and has been playing important role in transforming fibers into more useful forms (Branscomb, Beale, & Broughton, 2013). As carbon fibers and other advanced fibers with extraordinary properties have been developed, the braid technique has been tailored into various forms to fit the manufacture of advanced fiber reinforced plastics. Braiding technique can form a continuous composite part of a complex shape and is generally cost effective with low material waste. Braided forms have been widely used in aerospace and automotive industries due to their high stiffness and strength to weight ratio and versatility in terms of the geometry. A typical braiding process is demonstrated in Fig. 1. Bobbins which carry fiber reinforced materials are moving in a circular motion on the braiding plate which is usually stationary. Materials that have been drawn out from the bobbins will eventually fall on the center axis of the braiding plate to form a stable structure. If a mandrel is fed in, materials can be deposited and conformed to the surface

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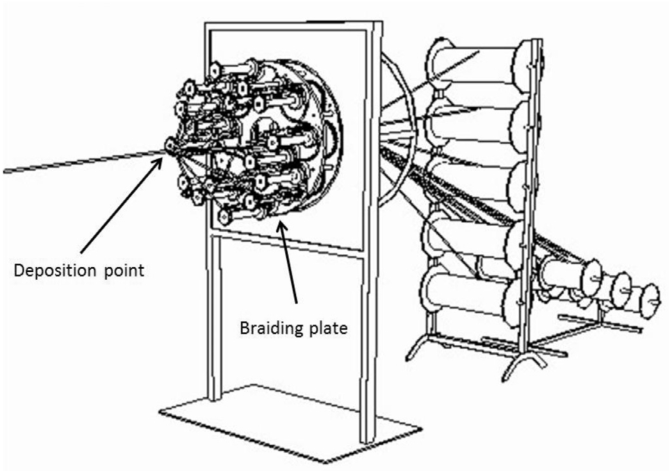

Fig. 1. A braiding process demonstration.

contour of the mandrel to generate a structure with exactly the same shape as the mandrel. A mandrel controlled by a robotic arm is fed in close to the deposition point and has a motion in the normal direction to the braiding plane, while the braiding plane on which bobbins are rotating is stationary.

The design and analysis of braided composite structures are more challenging because of multiple levels of complexity within the composite structure. In general, a braided composite structure is comprised of reinforcing fibers and a matrix. Thousands of individual fibers form tows which when interlaced with other tows form a complicated reinforcing architecture called a preform. Typically, the preform is subsequently combined with a matrix material into a desired shape to complete the part. Multiple constituent materials and sub elements make the composite structure highly anisotropic and heterogeneous. Finite element analysis (FEA) is a robust tool useful to overcome the complexity of predicting the properties of braided composites. But the realistic geometrical representation of a braided structure with complex contours is difficult to generate. As a result, a compromise is made by homogenization on the representative volume element (RVE). Instead of building and analyzing the actual braided structure, the FEA process generally performs the analysis on the RVE to obtain the homogenized elastic constants. Solid or shell elements with the properties derived from homogenized elastic constants will be used to model the whole geometry. This process is usually referred to as multiscale/multilevel modeling (Carvelli & Poggi, 2001; Lomov et al., 2007; Shen, Meir, Cao, & Adanur, 2015). A complete multiscale modeling process generally consists of models at three levels of hierarchy: a microscale model, a mesoscale model, and macroscale model. A microscale model derives the properties of interest of tow bundles from fibers and matrix materials. A mesoscale model then computes the properties of interest for the RVE from derived properties of tows. Finally, the properties of interest for the RVE will be used as smeared properties for solid or shell elements in a macroscale model. The elegance of the multiscale model is that it only performs the analysis within the RVE at each sublevel and exports the output to the next level mode using a homogenized material property. So it is computationally efficient while still considering the structures and properties at each hierarchy. However, the homogenization of RVE is not an ideal solution for braided structures on complex shapes because material orientation and fiber volume fraction may be different at every location throughout the part. In other words, unlike a uniform woven fabric composite which can be made by repeating a single RVE, a complex braided structure consists of numerous RVEs, each of which has different geometry. If the actual braided geometry is used in FEA, it will not have this issue and the RVE homogenization step at mesoscale level will be skipped. Therefore, the generation of actual braided geometry can ease the pain of defining material orientation in FEA of braided composites and push it to a more accurate level.

A general method to quickly generate braided topology on arbitrary shape with any non-concave cross-section is proposed in this paper. The term topology instead of geometry is used here because the model actually describes the spatial relationship between the center points on yarn path. As long as the center points are obtained, a certain cross-section can be swept along the curve formed by the center points to generate a solid object. Firstly, the kinematic equations are used to generate the basic formation of braided structure with yarn interlacing. Secondly, the mandrel will be decomposed along the braiding direction section by section. Each section is defined with a cross-section and a centroid point. The centroids will be aligned collinearly on the Z axis and the cross-section planes will be oriented perpendicular to the Z axis to form a new mandrel. Thirdly, all the nodal coordinates obtained from the kinematic equations will be translated in radial direction such that they will be conformed to the contour of cross-section at each section. Lastly, translations and rotations will be performed on all nodal coordinates such that they will match the shape of original mandrel. The methodology only involves sinusoidal functions and 3D translation and rotation based on tensor calculations. So it can be easily implemented in any sort of computer aided tools. The whole model is implemented in the Python programming language.