3D-HEXAGONAL BRAIDING: POSSIBILITIES IN NEAR-NET SHAPE PREFORM PRODUCTION FOR LIGHTWEIGHT AND MEDICAL APPLICATIONS

F.Schreiber[1*], K. Theelen[2], E. Schulte Südhoff[1], H.-Y. Lee[1], F. K. Ko[2], T. Gries[1]
[1] Institut für Textiltechnik of RWTH Aachen University, Aachen, Germany, [2] Advanced Fibrous Materials Laboratory, University of British Columbia, Vancouver B.C., Canada
* Corresponding author (fabian.schreiber@ita.rwth-aachen.de)

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1 Introduction

Braids provide an ideal preform for textile composite materials, while the structure of braids is restricted by the machine braiding procedure [1]. One major limitation of three-dimensional (3-D) braided composites is that the maximum preform size is determined by the braiding machine size. Furthermore most industrial machines are only able to braid preforms with a small cross section. Balancing the yarn length is especially a challenge for the braiding of micro filaments [2,3].

Therefore a novel and unique hexagonal braiding procedure was developed in collaboration between the Advanced Fibrous Materials Laboratory (AFML) of University of British Columbia, Vancouver (Canada) and the Institut für Textiltechnik (ITA) of RWTH Aachen University, Aachen (Germany). The 1st generation of the 3D-hexagonal braiding machine introduced in [4-6] is capable of handling micro filaments and manufacturing complex shaped three-dimensional braided structures (Fig.1). Within the prior work it was shown that the ratio of the machine bedplate size to the product cross-section size compared to common 3-D rotary braiding machines could be minimized, and more flexibility in manufacturing complex, variable cross-section braided fabrics has been achieved. Currently a 2nd generation braiding machine was put into operation including several improvements, in particular machine robustness, speed, flexibility and machine control.

In this paper the current machine design in particular the electrical control unit and the software development will be shown. Furthermore the structure and the mechanical properties of 3D-hexagonal braids will be shown and compared to 3D-rectangular braids.

2 Hexagonal braiding machine and fabrics

2.1 Machine design improvements

By developing an improved hexagonal braiding machine the up-to-date lab prototype was taken to the next level on the way to an industry ready machine (Fig.2). Machine design improvements include an additional switching device between two adjacent cams. By adding this switching device, similar to devices known from traditional lace braiding machines and as described in [3,7], between two adjacent cams, two carriers can take position between two cams and thereby the carrier number is increased significantly.

Further by using hybrid high-torque stepper motors in particular machine speed, accuracy and robustness are improved. The implemented stepper motors have a step-angle of 1.8° per step and a holding torque of 0.9 Nm. They can be either used in full step, half-step or micro step mode. The cam motors are equipped with a gear box additionally to provide a gear reduction of 1:9 to utilize a 60° movement and to realize an increased holding torque.

2.2 Machine control unit and software

All cam and all switching device motors are individually controllable and movable in order to get the full flexibility of the braiding machine. 37 motors are used to move 7 cams and 30 switching devices. All motors are equipped with a stepper driver individually which is directly triggered by a digital I/O card. The software architecture is specifically designed to suppress the movement of certain elements which interfere with the movement of other elements in order to avoid a collision or even a damage of the components.

$$n = 2x_{max} + 1 = 2 \cdot (4s - 2) + 1 = 8s - 3 \qquad (1)$$

$$m = 2y_{max} + 1 = 2 \cdot (2s - 1) + 1 = 4s - 1 \qquad (2)$$

All the motor command operations are stored in an array with height m and width n (see equation 1 – 2). Whereby x_{max} and y_{max} are the maximum extensions in X- and Y-axis direction (see equation 3 – 4) of cams next to each other and s is the side-length (in cams) of the hexagonal arranged cams.

$$x_{max} = 2r = 2 \cdot (2s - 1) = 4s - 2 \qquad (3)$$

$$y_{max} = r = 2s - 1 \qquad (4)$$

It is possible to store a sequence of instructions which makes saving of certain braid patterns as well as constant repeat of certain sequences possible. Further the software has a reset option which makes the return to individually designable zero-positions possible. Fig. 3 shows the program architecture of the machine control software and the information flow. The fact that all switches are connected in series is a very important part of the software. This does not only guarantee that the “State Array” is passed to all switches, but also that several switches next to each other cannot be transferred at the same time to avoid collisions of switching devices and cams as mentioned earlier.

2.3 Braiding patterns

Braiding patterns for solid and multilayer 3-D braided structures with various shapes were developed (Fig. 4). Furthermore similarities and differences to existing historical or common used braiding patterns were emphasized. In addition, multi-layer structures with various sizes, cross sections and interlinks have been realized. This emphasizes the advantage of the 3-D hexagonal braiding machine to manufacture complex and variable shapes. In comparison to common 3-D rotary braiding machines, both, multi-layer and solid 3-D braided structures, can be produced. In order to develop a certain braiding pattern for a special braid structure several examples from literature especially from [8] were taken into consideration. For each example a motor command file was implemented. An example for such a motor command file for a circular braid with 12 and 18 yarns is shown in Fig.5.

3 Results

Common 3-D rotary braiding machines are mainly capable of producing coupled square shapes, which can be enlarged to L- or I-beams. In addition it is possible to use several other braiding patterns and combinations. Braiding patterns for solid square braids with various size and yarn number were realized. Furthermore, structures with round and triangle shapes are able to manufacture (Fig.6 and Fig.7).

It was shown that it is possible to braid the same structures with a 3-D hexagonal braiding machine. Further the current machine prototype is especially designed for medical use in clean room environment. All machine parts are manufactured from FDA approved materials and the lubricants are reduced to a minimum. If lubricants are used they are also FDA approved or the specific machine part is separated from the braided good. A state of the art carrier system is used for bobbin storage during the braiding process. Wire materials smaller than 20 µm in diameter and 16 Denier fibres can be processed on the braiding machine.

In conclusion it can be said that especially solid three dimensional round and multilayer tubular shaped structures (Fig.8) are efficient to manufacture, and lead to highly and evenly integrated interlinked braids thereby creating new possibilities in preform production for lightweight and medical applications. Interesting applications could be yachting and ski poles, construction parts, arm and leg prosthesis and bifurcated stents and stent grafts.

Fig.1. 1st generation hexagonal braiding machine

Fig.2. 2nd generation hexagonal braiding machine

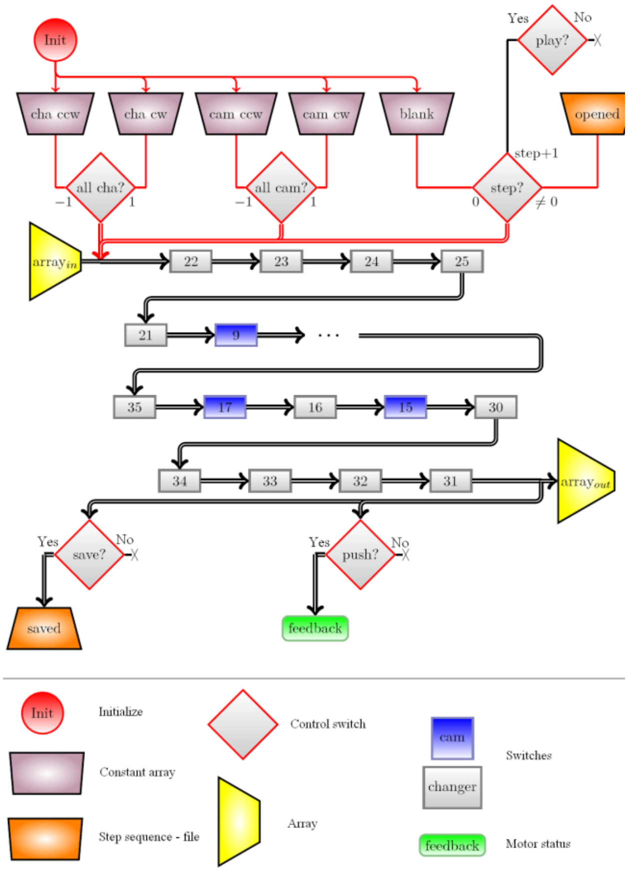

Fig.3. Program architecture and information flow of the machine control software.

Hollow	Solid	Multilayer	Advanced Shapes
Square	Square	Square	I-Beam
Rectangle	Rectangle	Rectangle	L-Beam
Round	Round	Round	T-Beam
Triangle	Triangle	Triangle	O-Beam with Strands
Hexagon	Hexagon		Bifurcation
	Star		

Fig.4. Braiding pattern for a 3D solid square structure with two yarn groups (left) and the braided fabric (right)

motor	step 1	step 2	step 3
0-1	3x CW	-	-
1-1	-	3x CW	-
1-2	-	-	3x CW
1-3	-	3x CW	-
1-4	-	-	3x CW
1-5	-	3x CW	-
1-6	-	-	3x CW

motor	step 1	step 2	step 3
0-1	3x CW	-	-
1-1	-	2x CW	-
1-2	-	-	2x CW
1-3	-	2x CW	-
1-4	-	-	2x CW
1-5	-	2x CW	-
1-6	-	-	2x CW

Fig.5. Motor command files for circular braids; 12 yarns (left) and 18 yarns (right)

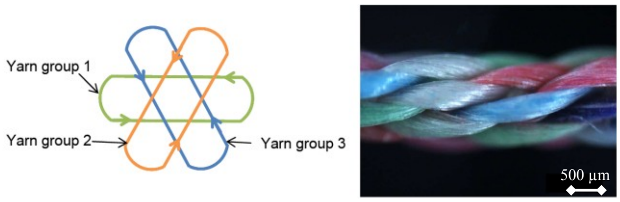

Fig.6. Braiding pattern for a 3D solid round structure with three yarn groups (left) and the braided fabric (right)

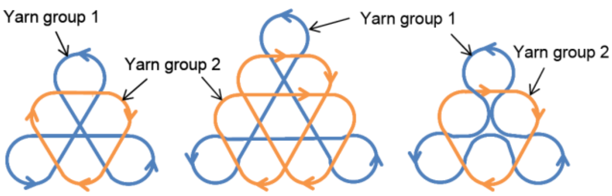

Fig.7. Braiding patterns for several 3D solid triangle structures

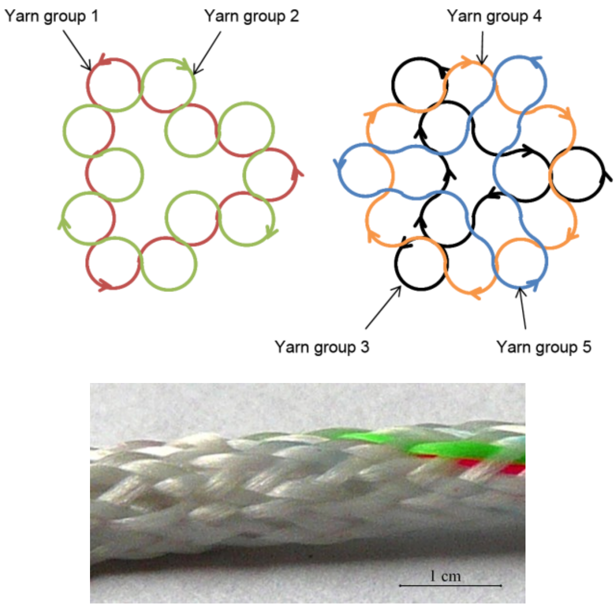

Fig.8. Braiding patterns for multilayer 3D tubular structure with two layers (top) and picture of the braid structure (bottom)

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