NOVEL THREE-DIMENSIONAL BRAIDING APPROACH AND ITS PRODUCTS

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ABSTRACT

A new braiding mechanism capable of fabricating complex shaped two-dimensional and three-dimensional composite structures, as well as the structural geometry of this novel 3-D braid, is introduced in this paper. This new 3-D braiding process is based on a hexagonal principle and may lead to a new family of complex fiber architectures particularly for medical and a broad range of structural composite applications.

Keywords: braiding, three-dimensional, implants, micro fibres, hexagonal composites

HEXAGONAL BRAIDING CONCEPT

Hexagonal close packing is the closest packing known. Examples in nature are the honeycomb or the packing of carbon nanotubes. The realization of hexagonal packing is based on the arrangement of three circles, wherein the center points are each equal to a corner of an equilateral triangle and they have a common point of intersection in the balance point of this triangle. The unit formed by this arrangement is shown in Figure 1. Joining six of these single units together to form a hexagon thus creating hexagonal packing of seven circles, referring to as the basic unit, is created as shown in Figure 2.

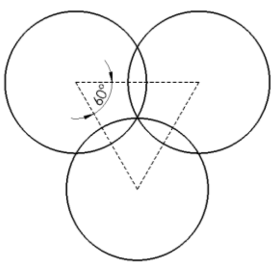


Figure 1: Single Unit

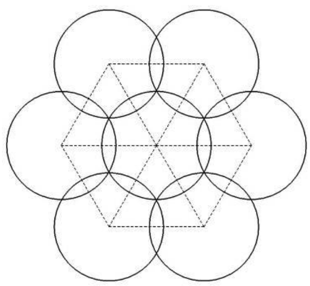


Figure 2: Basic Unit

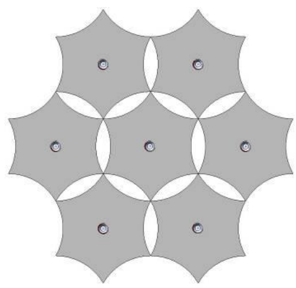


Figure 3: Hexagonal cam packing

The footprint of the mechanical realization of this packing is illustrated in Figure 3. This unique cam arrangement allows every cam to carry a maximum number of six carriers placed in sixty degree intervals around the cam, though only one carrier is allowed to take a mutual position between two adjacent cams, and therefore six different directions of planar carrier movement. The foot part of the carrier is designed as a glider whereby the bobbin is gliding during movement from one position to the other by using the adjacent carriers as a bearing surface. Compared to traditional four bobbin carriers which are capable of moving carriers in four different planar directions this unique hexagonal cam arrangement adds two more planar movement directions to the process. A scheme of a possible cam arrangement of 18 cams is shown in Figure 4.

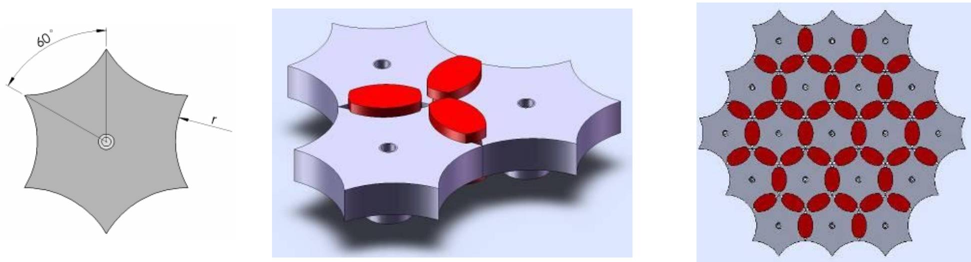


Figure 4: Advanced Fibrous Materials Laboratory 3-D rotary braiding approach.

PROTOTYPE REALIZATION

The first prototype machine following the hexagonal concept was designed and manufactured at the Advanced Fibrous Materials Laboratory (University of British Columbia, Vancouver, Canada) in cooperation with the Institut für Textiltechnik (RWTH Aachen University, Aachen, Germany). [1] The prototype incorporates 37 cams arranged in four concentric hexagons (1 + 6 + 12 + 18 = 37 cams) as shown in Figure 5; this machine can accommodate 132 carriers plus 37 axial yarns. This new braiding machanisme belongs to the well known braiding approaches described in [2-4].

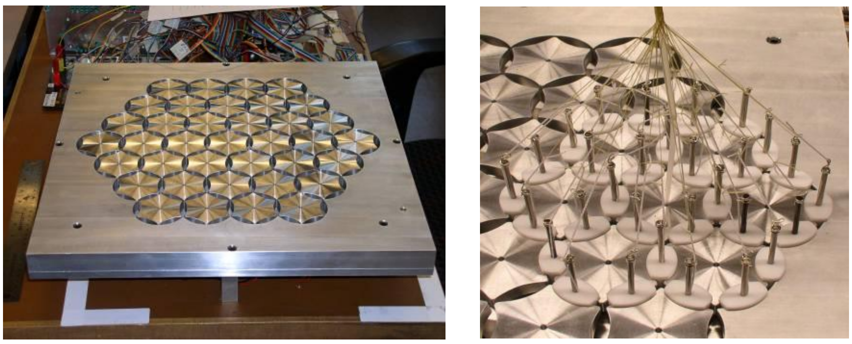
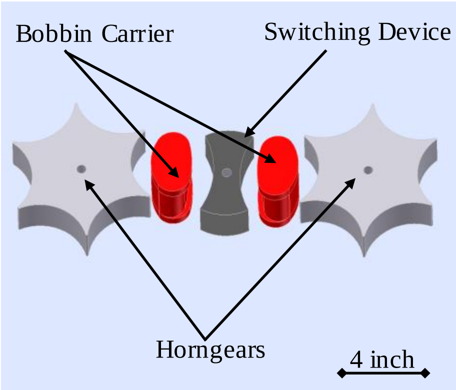


Figure 5: AFML hexagonal 3D-rotary braider.

Recently a second advanced prototype is designed at the Institut für Textiltechnik. By adding a switching device, similar to devices known from traditional lace braiding machines and as described in [5, 6], between two adjacent cams, two carriers can take position between two cams and thereby the maximum possible number of carriers is achieved. This advanced hexagonal three-dimensional braiding approach is illustrated in Figure 6. The final prototype machine will incorporate 61 cams arranged in five hexagonal rings being able to accommodate 366 yarn carriers and 61 axial yarn carriers.



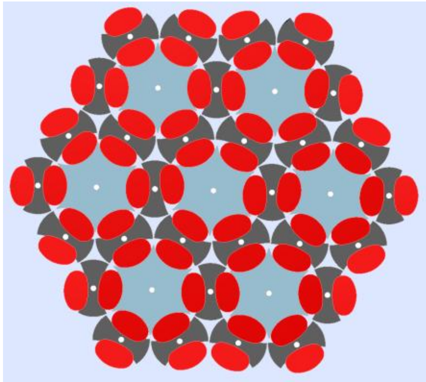


Figure 6: Advanced hexagonal 3D-rotary braiding approach.

Compared to the first prototype machine concept, where with an arrangement of for example 18 cams, 36 out of 108 cam wings had to be kept empty. The advanced cam arrangement makes it possible in this case to use all 108 cam wings. Thereby the carrier number is increased rapidly compared to present 3-D rotary braiding approaches. [21] In Figure 7 the design of the new machine prototype is illustrated. Every horngear and switching device is driven by an individual stepper motor, therefore adding maximum flexibility to the manufacturing process. The final prototype version will be equipped with more then 200 stepper motors which leads to the need of a micro processer control unit to organize the highly complex hexagonal braiding process.

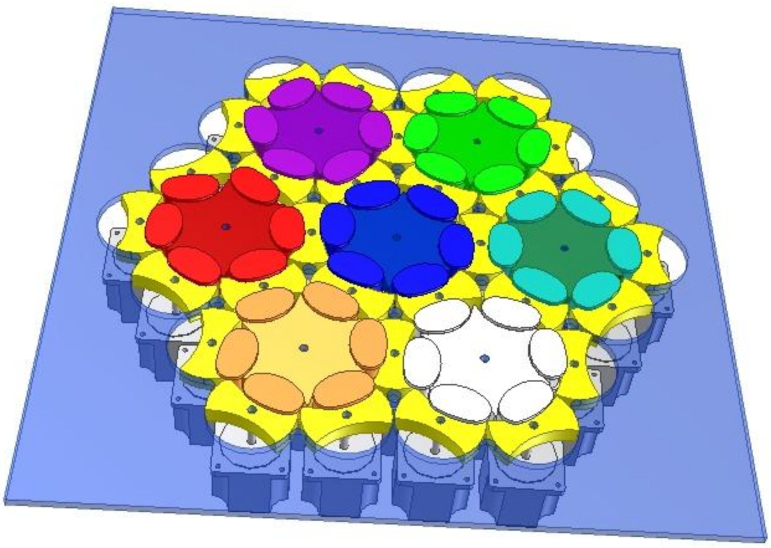


Figure 7: Design of advanced hexagonal 3D-braiding machine.

GEOMETRY OF HEXAGONAL BRAIDS

The hexagonal cam arrangement makes a wide variety of braiding patterns possible. Using the advanced hexagonal approach even more patterns can be realized.

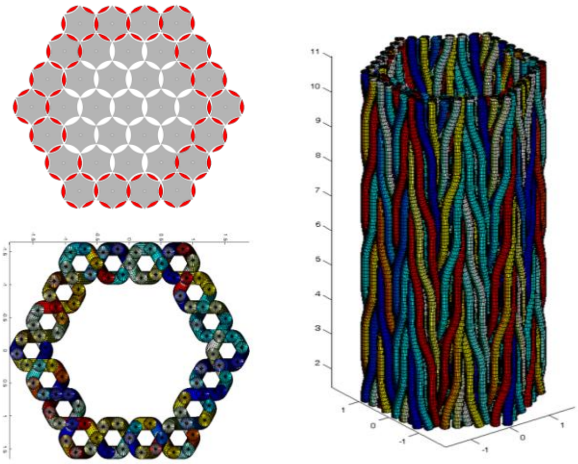


Figure 8: Machine setup (current prototype with 90 yarn carriers) and simulation (MATLAB©) of braided hollow HEX-beam

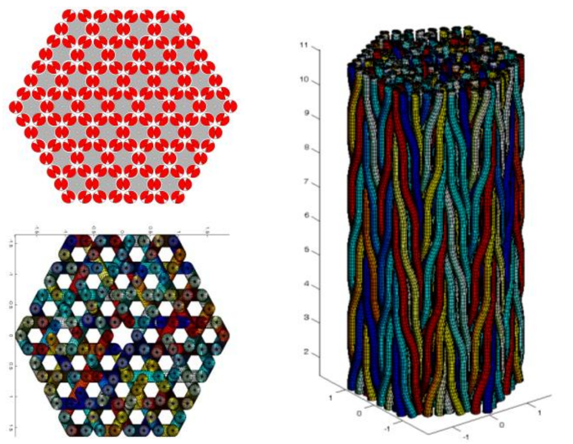


Figure 9: Machine setup (advanced prototype with 222 yarn carriers) and simulation (MATLAB©) of braided solid HEX-beam

Figure 8 shows a braiding setup of the current hexagonal braiding machine. The pattern incorporates 90 yarn carriers and the simulation shows a braided hollow hexagonal beam. In comparison to Figure 8, Figure 9 shows a braiding pattern and simulation of the advanced prototype for a solid hexagonal beam (braided with 222 yarn carriers). Both setups refer to a 37 cam machine.

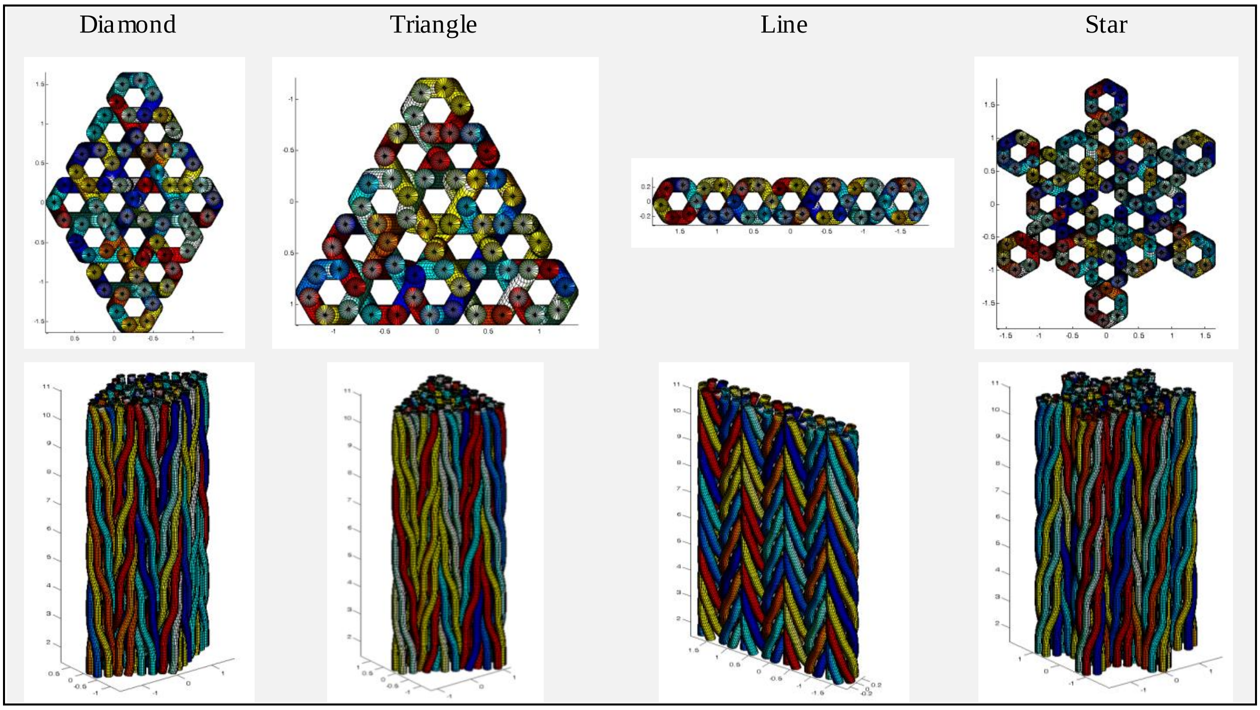


Figure 10: Selection of hexagonal braiding patterns and simulations (MATLAB©).

A selection of braiding patterns (shown in Figure 10) demonstrates the flexibility of the hexagonal braiding technology. The patterns range from traditional line/lace or circular braiding to complex three dimensional braiding patterns like triangle, diamond or even star shape.

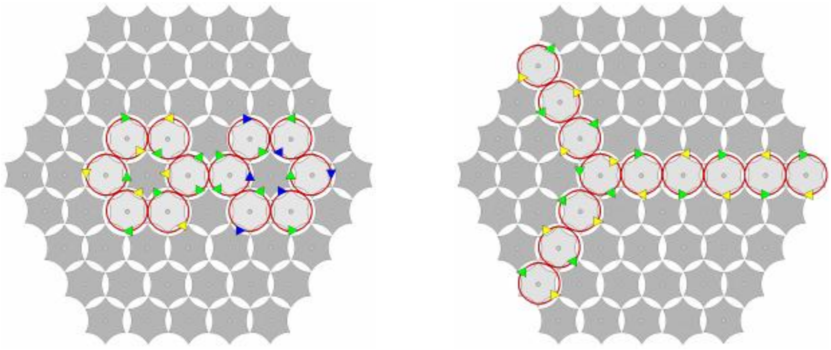


Figure 11: 3D-braiding patterns: Double-tubular (left) and Y-beam (right).

As illustrated in Figure 11 the hexagonal cam arrangement allows, in addition to the current braided structures as described in [8-11], the production of double tubular fabrics and various beams like Y-beams. Other tubular or beam structures are for example: X-beam, λ-beam, barbell-shape, multi-tubular, or hex-beam with strands. Furthermore because of the hexagonal ring arrangement of the cams it is possible to braid with multiple different materials at the same time by using multiple "circular braiders" at the same time and thereby manufacturing a multi-layer tubular or otherwise shaped braided structures. In addition the realization of multiple ramifications is also possible. By switching between different braiding setups shapes can be joined and split in various combinations.

PRODUCTS AND APPLICATIONS

Coronary bifurcations are prone to develop atherosclerotic plaque due to turbulent blood flow and high shear stress. These lesions amount to approximately 15% of the total number of coronary interventions. [7]

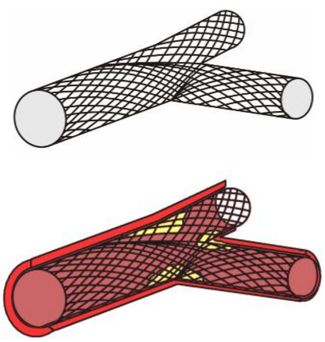


Figure 12: Potential stent design for bifurcation stenosis treatment.

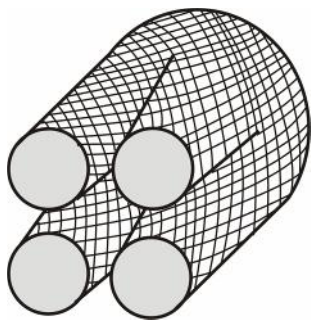


Figure 13: Quadruple ramification braid.

Various two-stent techniques have emerged to allow stenting of a bifurcation stenosis. The state of the art in bifurcation stenting is the double stenting stents using different techniques. [7] Therefore the surgeon has to implant two stents in two procedures, which increases time of surgery and influences the outcome. One of the improvements using the 3D-braiding capabilities of the novel braider is to produce multi-dendritic circular braids. Therefore a potential application for hexagonal tubular braids is a bifurcation stenosis stent for bifurcation stenosis treatment as shown schematically in Figure 12. Multi-tubular structures as shown in Figure 13 are interesting for a variety of other cardiovascular implants for example for entire artery section replacement.

Furthermore by utilizing the hexagonal ring arrangement the production of stent-in-stent applications like multi-layer stents (Figure 14) is possible. These stents could be used for aneurysm treating by varying the compactness of selective braid areas and thereby preventing blood flow through this area. Another field of applications in the medical sector are braided fabrics for catheter-reinforcements and braided suture material.

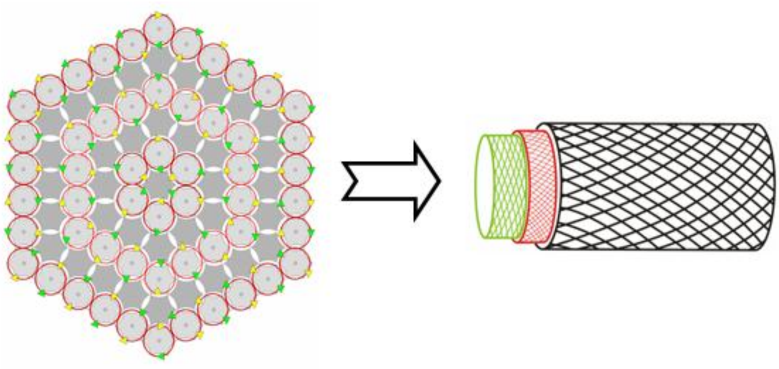


Figure 14: Multi-layer stent and braiding set up therefore.

In addition to medical implants hexagonal braiding technology is also well suited for composite structure applications. The unique and novel structures could lead to a new field of micro composite or present composite applications such as reinforcements or highly resistant micro devices.

SUMMARY

In this paper we introduced the most recent advancement in 3D braiding technology. Specifically, motivated by the needs of a new family of medical devices, a novel hexagonal 3-D rotary braiding system utilizing hexagonal horngears has been developed. This novel braiding process provides considerable advantages over the traditional 3-D orthogonal rotary braiding approaches. It is envisioned that, as we learn more about the hexagonal braiding process, new structures and shapes will be developed that will lead to new functions thus new applications beyond our current interest in medical devices and micro composites.

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