

# **DESIGN AND CHARACTERIZATION OF A NOVEL THREE DIMENSIONAL WOVEN-KNIT HYBRID FIBROUS PREFORM FOR COMPOSITE REINFORCEMENT**

## 1. Introduction

Evans developed and patented a new technique to produce three dimensional (3D) woven/knit hybrid structures to reinforce composites. He obtained two patents and started developing two prototype machines for this purpose [1, 2]. After Evans' death, the patent licenses and two prototype machines were donated to Auburn University, Department of Polymer and Fiber Engineering.

We are in the process to characterize, automate and optimize these novel three-dimensional hybrid weaving/knitting machines that combine weaving and knitting principles to produce novel 3D woven/knit structures using the state of the art electronic and robotic control concepts. A graduate student did the initial work on these machines [3,4]. However, there is a lot more to be done to make the full utilization of the patented technology.

## 2. Method and Material

### 2.1 Improvements on the Machine

In the first year of the project, the hybrid machine motions and fabric processing parameters were defined, studied and analyzed. Novel fabric prototypes were fabricated to establish the basic knowledge to understand the motions of active parts and their results on the production of 3D fabric structures. Design defects and problems on the prototype hybrid machines were identified.

Knitting is the main formation technique in this novel 3D hybrid fabric concept. The interaction between the knitting elements and the industrial yarns used was causing some processing problems. The root cause of these problems were investigated and analyzed.

Figure 1 shows the schematic principle of the fabric formation zone of the machine. The technique used for production of 3D hybrid fabric includes weaving principles (beat-up reed (2) and warp yarn supply (1)) and warp-knitting principles (bias yarn supply mechanism (8) and fabric formation motions (3,4,5,6,7)).

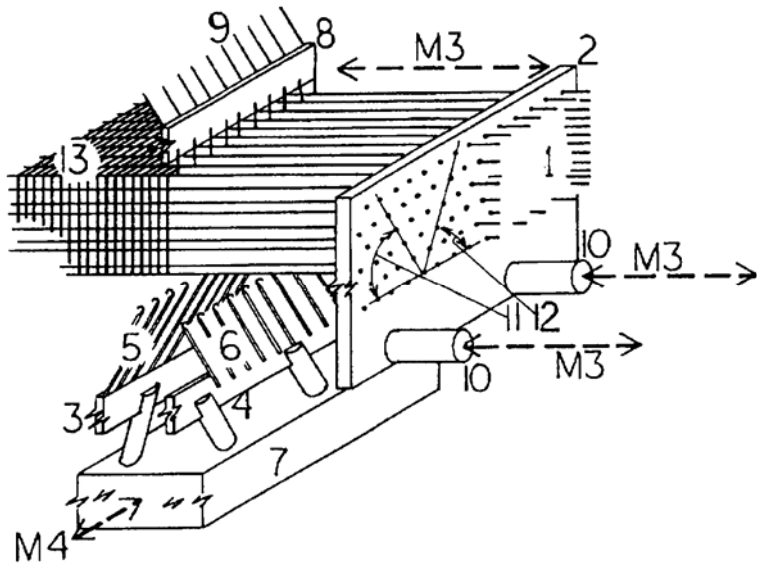


Figure 1. Schematic preview of hybrid weaving/knitting machine with selected parts [1,2].

The detailed sequence of operations of the major components of the hybrid machine was studied. The prototype machine, as received, was not suitable to produce any 3D structure continuously (Figure 2). Several improvements needed to make the hybrid machine suitable to produce samples. Problems related to the inappropriate insertion length, needle bar, needle bed shifting, cam timing, beat-up and take-up system were identified. Alignments were made on the needle strokes, because the needles were not rising high enough to catch the yarns. Arm-joint mechanism was adjusted to enable for further stroke. Because of uneven stroke among the four needle-bar arms, the needle bars were bent. This was causing mislocation of the bias yarn during insertion.



Figure 2. The front view of the prototype hybrid machine prior to the start of this project.

Shifting amount was determined with the interval between two consecutive holes on the reed and needle distance on the needle bar. The amount of shift on the hybrid machine was modified to enable sample production.

Cam timing is another parameter that was adjusted. The original settings of the cam did not allow bias yarn insertion. There were conflicts between the motions of each element. The needle bars collided with each other and did not follow the path that they should follow in order to insert the new bias yarn correctly without damaging the warp. The cams were readjusted based on the motions that must be performed to fabricate the expected fabric structure.

The hybrid machine was automated for continuous operation. As received, the tensioning mechanism on the machine contained only a positive tensioning system for bias yarns. However, it was not enough to keep the tension of the yarn constant, therefore 3D loop length variations occurred. Adding an additional negative tensioning system between the first and Z-yarn guide solved both the slackness in the fabric structure and working efficiency of the machine. A spring-loaded adjustable tensioning system was used which supplied the desired amount of yarn based on the theoretical loop length.

The beat-up system was unable to add the newly inserted yarn to the fabric fell. There was a stroke variation along the system. The length of the beat-up rod, that the reed is attached

to, was not long enough for proper beat-up. With proper modifications, the beat-up efficiency and variations were improved. The amount of abrasion on warp yarn caused by the needles and the reed was reduced. Figure 3 shows the 3D hybrid machine after the modifications mentioned above.



*Figure 3 The front view of the prototype hybrid machine after the modifications*

## 2.2 Three Dimensional Fibrous Structure Manufacturing and Processing

There were some limitations for the materials that can be used in the production of 3D fabrics. The fiber origin and its characteristics were not taken into consideration in the original hybrid machine design. Although the hybrid machine was designed for industrial yarns, the brittleness of the fibers was not considered in reed design. The holes in the reed are opened square in cross-section, but without any rounding of the edges. The sharp edges are the main limitation for the usage of high performance industrial yarns that are well known for their extreme sensitivity to sharp edges because of their brittle nature more than other fibers. Sharp edges with highly abrasive materials (like metal parts) cause high tensile stresses. Hence, lubricated flexible hollow cylindrical polyethylene guiding tubes were used to increase the radius of curvature and reduce the stress concentration. After the modifications, samples of novel 3D fibrous structures were produced on the machine (Figure 4).

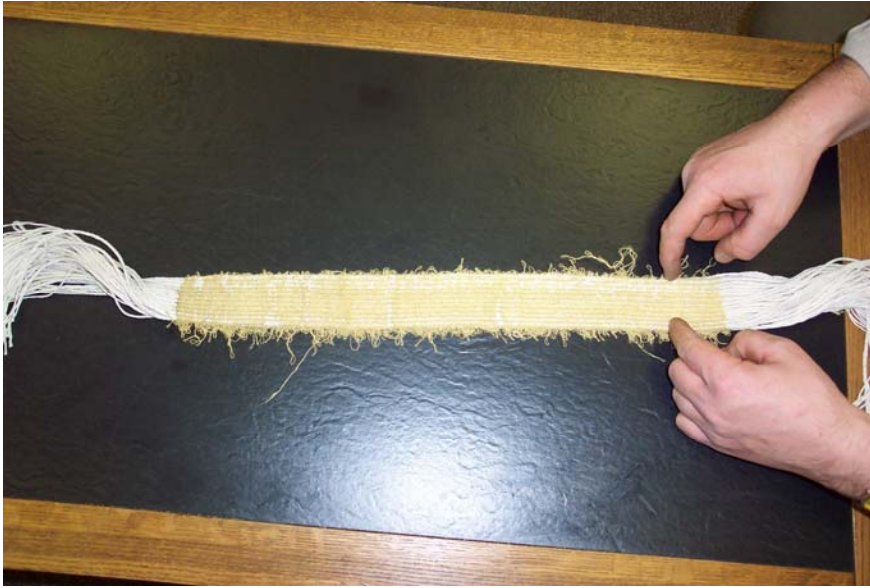


Figure 4. 3D hybrid woven/knit composite reinforcement structure

The characteristics of the yarns used in the 3D fabric specimens are as follows:

Warp Yarn: Polypropylene, 4 ply, each ply is continuous with a denier of 2565.

Filling (Stitch) Yarn: Kevlar® aramid, with a denier of 315.

### 3. Results and Discussion

A composite beam that is reinforced by the novel 3D fabric structure was produced using the vacuum bag technique as shown in Figure 5. The composite structure was tested for bending characteristics using the 3-point (Figure 6) and 4-point bending tests (Figure 7) using the Instron 4505 machine.



Figure 5 Composite manufacturing with vacuum bagging technique

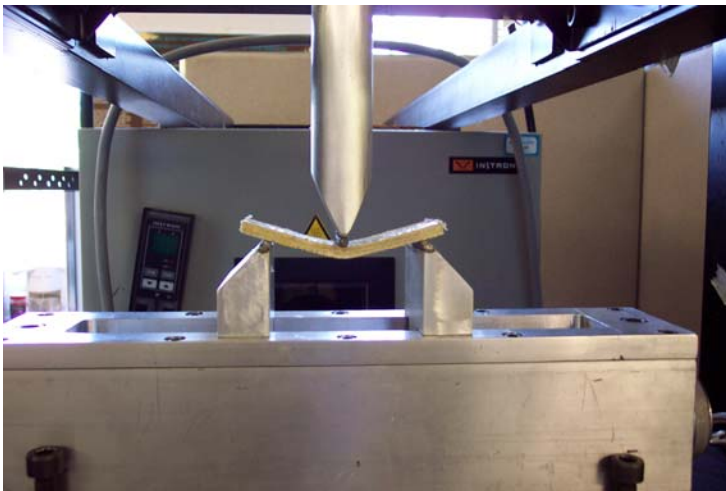


Figure 6 Three-point bending test of the composite

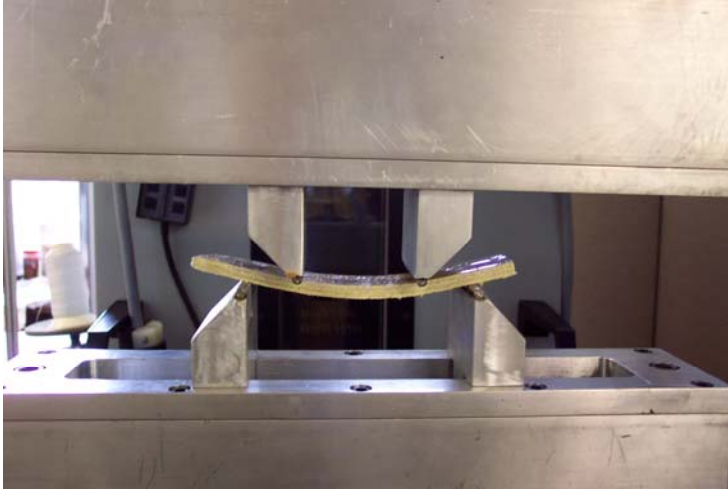


Figure 7 Four-point bending test of the composite

Figures 8 and 9 show the load-elongation diagrams from the three-point and four-point tests, respectively.

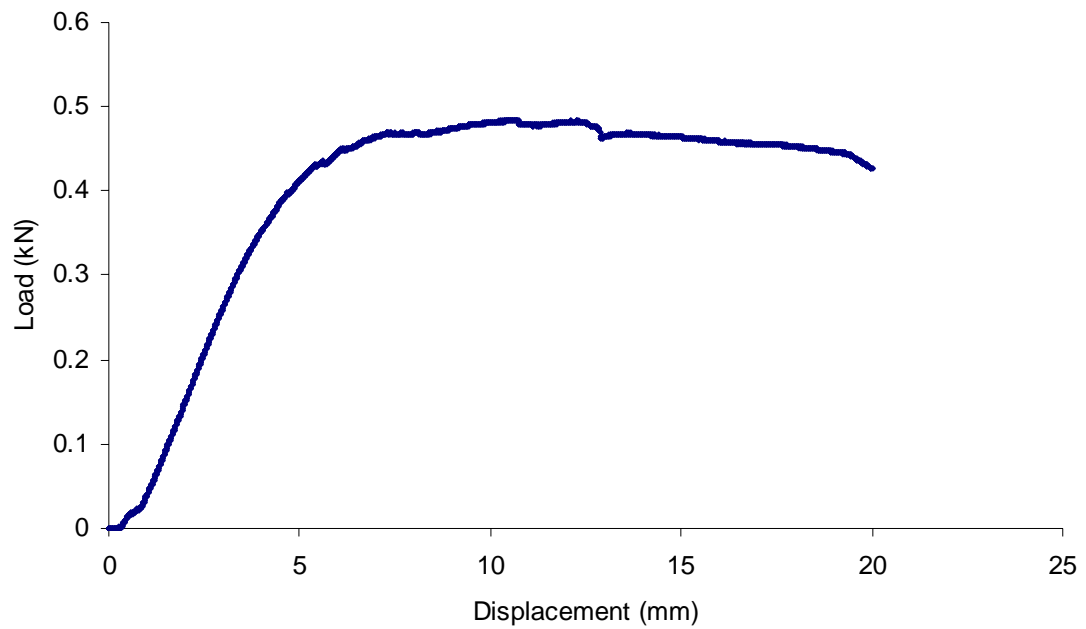


Figure 8 Three point bending test result

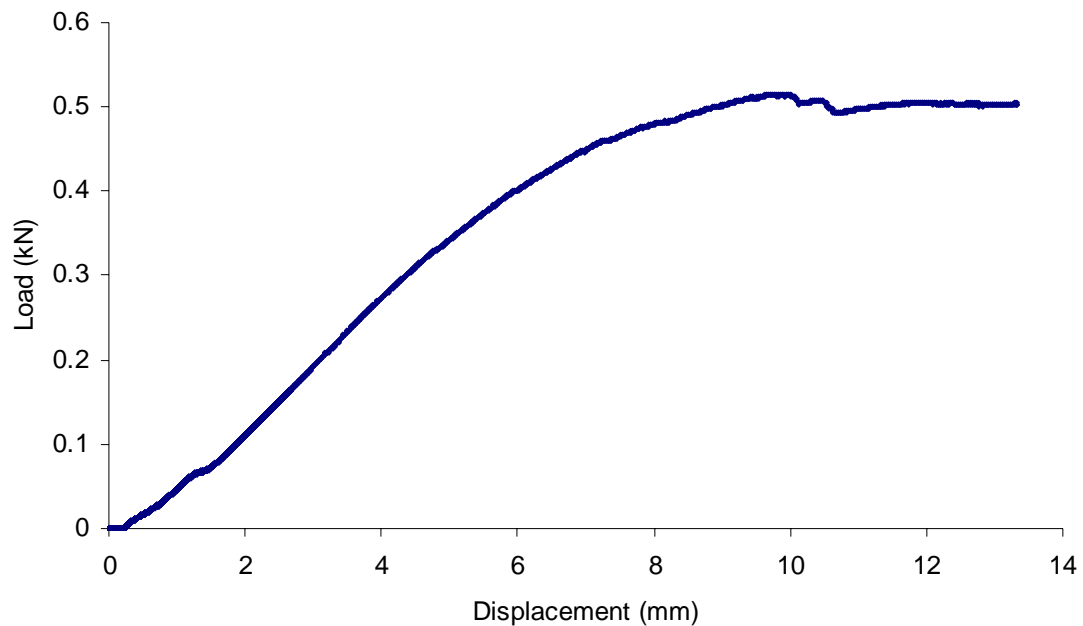


Figure 8 Four point bending test result

#### 4. Conclusions

Improvements have been made on the existing patented prototype machine that combines weaving and knitting principles. The machine has been automated to produce 3D fabric structures. 3D preforms were successfully manufactured on the machine. Composites were made using the preforms. Three-point and four-point bending tests were performed on the resulting composite structures. The results showed that this composite structure can be used where flexibility and toughness is needed.

#### 5. References

1. Evans, R., "Method, Machine and Diagonal Pattern for Three-Dimensional Flat Panel Fabric", U.S. Patent 5,791,384, August 11, 1998.
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3. Adanur, S., and Onal, L., "Analysis of a Novel 3D Hybrid Woven/Knitted Fabric Structure, Part II: Mechanical Model to Predict Modulus and Extension", *Textile Research Journal*, 74(10), 865-871, October 2004.
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