COMPUTER AIDED DESIGN FOR 2-STEP BRAIDING PREFORM

M. El-Messiry
Textile Engineering Department, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

The composite materials are widely used in different fields of industry, automotive, marine, aerospace, since it introduces a new materials with the outstanding mechanical and thermoelastic properties in addition to the capability of forming complex structure shapes. Thus, the 3-D braiding techniques are receiving greater attention. The principle aim of this work is to apply CAD in order to make it possible to design a complex shape 3-D braided structures of a specific dimensions and properties. Moreover, this program can be used to control the movement of the braiding yarn carriage on the automatic 2-step braiding machine.

1. INTRODUCTION

The composite structures have been used by the ancient civilizations. However, over the last two decades advanced composites have been developed to the state where they are now routinely used alongside with the engineering materials in a wide variety of applications [1,2] due to their high specific strength, high specific modules and low thermal expansion coefficient among others [3]. Another feature is their amenability to be designed or tailor made to suite the specific application for which they are intended.

The properties of any composite do not only depend on the reinforcement and matrix materials, but also on the geometrical arrangement of fibres and their interface with the matrix. The high performance fibre materials used in composites can be produced as;

1. 2-D weaving.
2. 3-D weaving.
3. 3-D braiding.

Mohammed M. [4] mentioned that the development of automated and preferably computer controlled 3-D weaving machine which are not limited to bodies of revolution is an argent matter.

The 3-D braiding gives the capability for the production of net shapes from all types of material, more over, the fibres architecture and their interface with the matrix can be easily changed, in order to design the required properties of the final preform.

Basically, there are now two different groups of 3-D braiding techniques, 4-step or 2-step depending on the machine configuration.

Popper and McConnell [5] in the year 1987 introduced the principle of the 2-step 3-D braiding, so it is considerably new. The arrangement of the machine consists of two sets of yarns, axial yarns placed in the preform axial direction, and braider moving between the straight stationary axials in a special pattern which cinches the axials in order to stabilize the shape of the preform.

Several investigations [3,4,6] have been made to produce differently shaped composites by the 2-step braiding process. Frank, K. Ko [6] mentioned that the tensile and flexural properties of the 2-step braiding composites for various proportions of axial and braiding yarns served to illustrate the design flexibility of this composite preform system. The unique feature of the 2-step braiding composite system has been identified to be its ability to incorporate a substantial amount of axial yarns in a 3-D truss like fibre network and the ability to form structural shape readily. Accordingly the 2-step braiding preform architecture is most suitable for thick structural shapes which calls for through thickness reinforcement without sacrificing axial properties.

The simplicity of the 2-step braiding process lands itself to easy automation resulting in potentially economical preform fabrication process with a use of data base this 2-step braiding composites will play an important role in the growing family of textile structural composites.

Li, Wei [10] gave a theoretical and experimental investigation for braiding structure. He suggests a relation of different parameters such as fibre orientation, yarn volume fraction and preform contour size, and pointed out the necessity of developing the integrated computer aided designing technology, and a software should be developed using the known structural geometries.

The objective of this work is to develop the required software to design preforms based on the required geometries of the composite structures. At the same time, it can be used for the driving computer controlled 3-D braiding machine.

2. NOMENCLATURE

d_a	diameter of axial yarns in a 2-step preform.
d_b	diameter of braiding yarns in a 2-step preform.
e	diameter ratio of a 2-step preform, (da/db).
G	number of braiding yarn groups in a preform.
h	preform pitch length (formed in one braiding cycle).
h_d	normalized pitch length of a preform, $hd=h/db$ for the 2-step preform.
L_c	projected length of all braiding yarns in one pitch 2-step preform on the preform cross-sectional plane.
m,n	number of axials arranged on the sides of a 2-step rectangular slab.
M_k	normalized machine side length.
n_s	number of slots in a 2-step machine.
N_a	number of axial yarns in a 2-step preform.
N_b	number of braiding yarns in a 2-step preform.
N	total number of yarns in a preform.
q	shape factor of the 2-step preform cross-section, $q=mn/(m+n)$.
R	yarn retraction, $R=L/h$.
S	distance between slots in a 2-step machine.
S_d	normalized distance between slots.
U	unit cell volume.
V	volume of the repeat unit.
v_b	braiding speed (cycles/min).
v_p	take-up speed (in/min).
V_y	yarn volume fraction of a preform.
W_k	normalized length of a side with k axials for a 2-step preform.
α	surface angle of the braided preforms.
γ	braiding yarn orientation angle for a 2-step preform.

3. 2-STEP PREFORM STRUCTURE PARAMETERS

For developing a computer modelling to simulate the orbits associated with the 2-step braiding, which is concerned in this work it is required the knowledge of the preform structure. The structure parameters of the 3-D braiding preform have been investigated by several authors [9,10]. Considering the 2-step preform of, m x n, the following geometrical relations are given:

a- structure geometry

- The number of axials is given by;

$$N_a = 2mn-m-n+1$$

- The number of braiding braiders is given by;

$$N_b = m+n$$

So that the total number of yarns in the structure is

$$N = 2mn+1$$

- The number of braider groups, G, can be calculated using the following formula;

$$G = \frac{m\,n}{\text{Least common multiple of m and n}}$$

- The ratio of braiders to axials in a preform is approximately given by;

$$\varepsilon = \frac{1}{2q-1}$$

- The total projected length of the braiders in one machine cycle structure is given by;

$$L_c = (d_a+d_b)[4mn-0.4292(m+n)]$$

- The average braider orientation angle, γ, is given by;

$$\tan\gamma = \frac{L_c}{(m+n)\,h}$$

- The surface angle of the braided preforms is given by;

$$\tan\alpha = \frac{\tan\gamma}{\sqrt{2}}$$

- The braider yarn retraction is given by;

$$R = \sec\gamma$$

- The preform contour size is given by;

$$W_k = (1.414k-0.414)(1+e)+1$$

Where k is the number of axials yarns in the considered side.

- The yarn volume fraction is given by;

$$V_y = \frac{\pi e^2}{4(1+e)^2} + \frac{\pi \sec\gamma}{2(1+e)^2(4q-0.4292)}$$

b- The mechanics of 3-D braid composites.

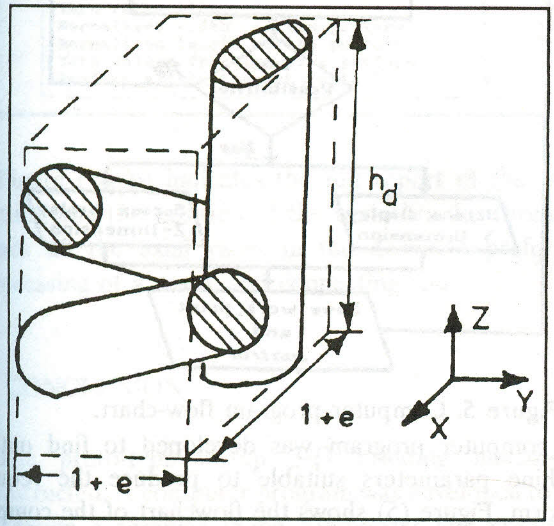


Figure 1. Unit cell of the 2-step structures.

The mechanical properties of 3-D braiding composites can be predicate with the knowledge of fibre properties matrix properties and fiber architecture. Considering a unit cell of the 2-step braided structure and its projections in different directions as shown in Figure (1), the tensile strength of the 2-step preform may be obtained by;

$$\delta_c = \delta_a\left[\frac{\pi}{4}.\frac{d_a^2}{(1+e)^2}.(1+\frac{2\cos^2\alpha}{\varepsilon e^2})\right]$$

$$SR = \frac{\delta_c}{\delta_a}$$

where:

δ_c - tensile stress of the preform,

δ_a - tensile stress of the axial yarn,

δ_b - tensile stress of the braider yarn,

ε - δ_a/δ_b,

SR - preform to axial yarn strength ratio.

While the strength of composites can be predicted by the rule of the mixture, thus by adding the strength of the matrix.

4. MANUFACTURING OF 3-D BRAIDING STRUCTURES

To produce different shapes of the 3-D braiding structures the 2-step proto-type braiding machine was designed and built in the TEXTILE ENG. Dept., Alexandria University. Figure (2) shows a photo of that machine. A wide range of structural shapes were prepared in an integral manner with 2-step braiding process. Figure (3) illustrates some of the designed shapes. The 3-D braiding samples were consolidated in a resin, Epoxy, in order to form a composite material. Figure (4) shows a cross-section of the composite indicating that the matrix was uniformly distributed around the fibre structure of the preform.

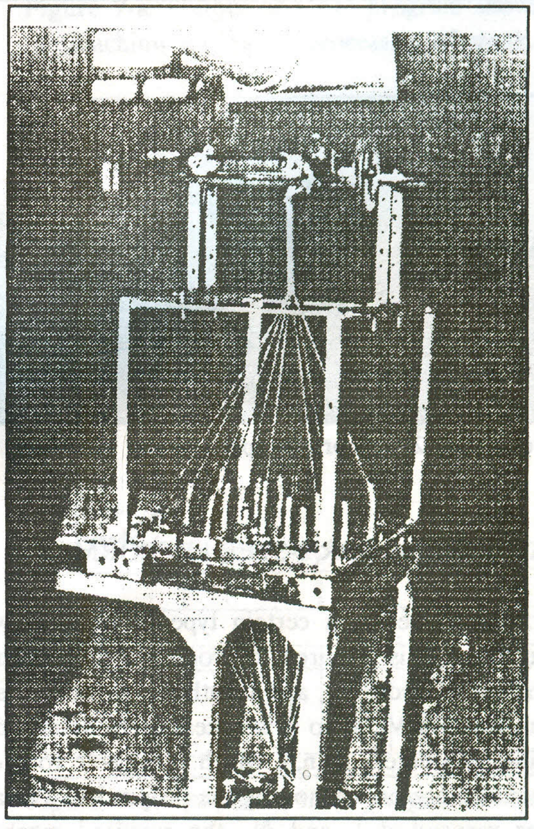


Figure 2. Cross-section of rectangle shape composite.

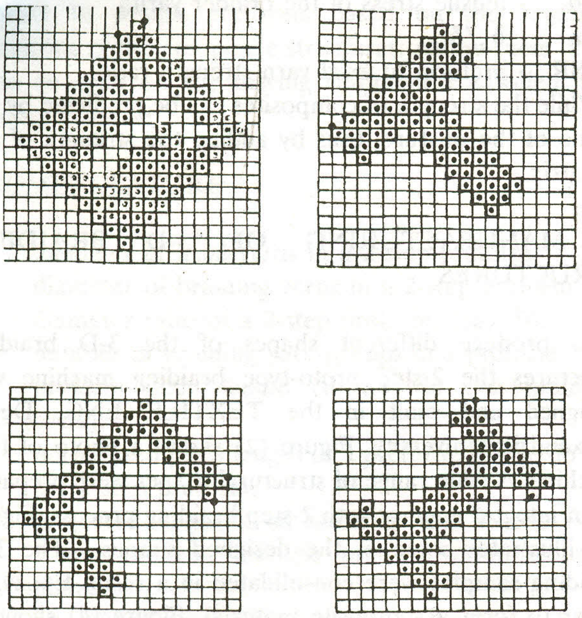


Figure 3. Machine arrangement for processing of the 3-D braiding structures.

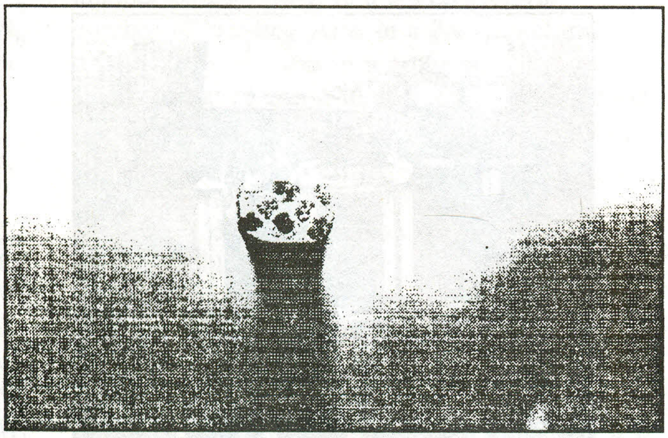


Figure 4. The 2-step proto-type braiding machine.

5. CAD SYSTEM FOR 2-STEP PREFORM

In order to design a certain type of preform with a simple shape, it is required to produce a preform having dimensions of width w_1, and length w_2, as well as a yarn volume fraction V_y. Also it is necessary to determine the machine parameters ,m,n,h, which is capable to produce the required preform. Knowing the properties of axial and braider yarns d_a,d_b,t_a and δ_b, the required mechanical properties of the composite parts can be calculated.

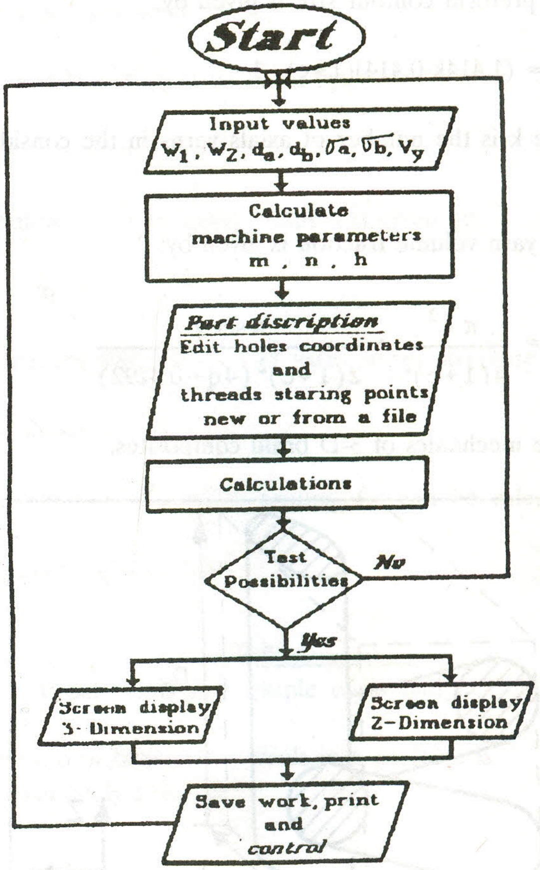


Figure 5. Computer program flow-chart.

A computer program was developed to find out the machine parameters suitable to produce the required preform. Figure (5) shows the flowchart of the computer program. Table (1) gives the machine parameters in the case of rectangular shape with $W_m = 40$, $W_n = 80$ and $V_y = 0.65$.

However, in the case of complex shaped preforms such as T,L,C or others with the holes inside the design, another algorithm should be developed, and the peculiarity of 2-step braiding machine must be considered. The design starts with the determination of the values m,n, that satisfy the required maximum length and width of the preform. Then the shape is preformed through the removal of certain number of the axial yarns.

The developed computer program gives us the ability to design any shape of braiding structures, as well as to follow the path of each braider yarn. Two and three dimensional drawings of the designed shape are given. Figures (6-a,b,c) show some examples of the designed parts. More complicated designs can be worked out by the use of the above developed program such as a connecting rods and a circular shaft.

Table 1.

Input data :

Axial yarn diameter	d_a	2
Braider yarn diameter	d_b	1
Tensile ratio of axial / braider yarn	El	1
Normalized width of the preform	W_m	40
Normalized length of the preform	W_n	80

OutPut data :

1	Machine setting

Number of axials in X direction	m	9
Number of axials in Y direction	n	18
Normalized pitch length	h_d	1.5

2	Preform expected parameters

Shape factor	q	6
Surface angle of the braided preform	α	1.54
Yarn retraction	R	47.15
Normalized width of the preform	W_m	37.94
Normalized length of the preform	W_n	76.11
Yarn volume fraction of a preform	V_y	0.70
Preform axial strength ratio	SR	0.35

Figure (7-a,b) indicates the full report of the machine setting and the position of the main braider threads that cinch all the axial yarns in the designed preform, for processing of a crank and connecting rod.

6. CONCLUSION

The proto-type 2-step 3-D braiding machine was constructed. A computer program was developed to enable to design a complex shape composites and predict their tensile properties.

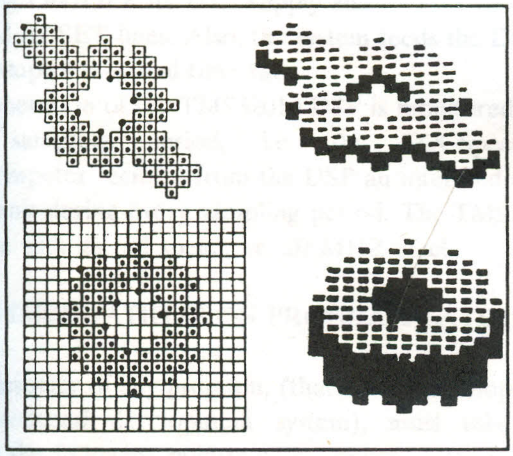
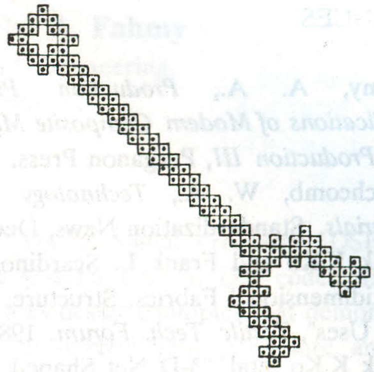


Figure 6. Machine arrangement for processing of the propeller and hollow shaft.



No. Rows : 10
No. Columns : 30

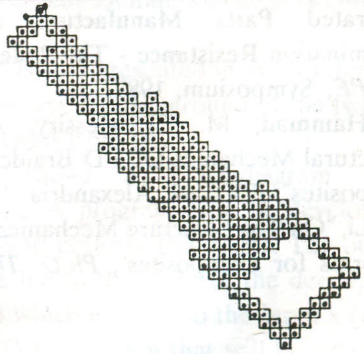
No. Threads : 6

No.	X	Y	Direction of Movement
1	10	9	D
2	14	9	D
3	50	3	D
4	50	19	R
5	5	10	U
6	48	7	D

No. Holes : 9

No.	X1	Y1	X2	Y2
1	4	10	6	12
2	53	7	61	15
3	1	1	49	7
4	1	15	49	21
5	9	7	47	9
6	9	13	47	15
7	49	1	57	3
8	49	19	57	21
9	51	9	53	13

Figure 7-a. Output of CAD program showing the machinw setting for processing of crank.



No. Rows : 8
No. Columns : 30

No. Threads : 2

No.	X	Y	Direction
1	2	5	D
2	1	8	R

No. Holes : 6

No.	X1	Y1	X2	Y2
1	4	8	6	10
2	50	4	58	14
3	1	1	21	5
4	0	1	41	3
5	1	13	21	17
6	21	15	41	17

Figure 7-b. Output of CAD program showing the machine setting for processing of connecting rod.

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