THE EFFECT OF PITCH LENGTH ON TORSIONAL RIGIDITY AND RELAXATION OF 3-D BRAIDED GRAPHITE/EPOXY COMPOSITES

Mohamed Hammad, Magdy El-Messiry
Textile Department, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

and Aly El-Shiekh
Mars Mission Research Center, College of Textile,
North Carolina State University, Raleigh, U.S.A.

ABSTRACT

Torsional rigidity and relaxation are among the important properties which determine using a composite material as a load bearing element. In this paper, the effect of the pitch length of the substrate on the torsional rigidity and relaxation of 3-D braided Graphite/Epoxy composite material is experimentally assessed. The testing specimens are produced on the 4-step (or Cartesian) 3-D braiding process with the 1 x 1 braiding pattern. The specimens are prepared using 12-K Carbon fibers as a substrate and Epon 828 resin as a matrix. Different pitch lengths are achieved through using different operating conditions. After the specimens being twisted, damages introduced are studied. Results reveal that the pitch length of the braided substrate plays a significant role in affecting the torsional rigidity and relaxation of the composite material.

Keywords: Braid, 3-D Structure, 2-Step, 4-Step, Graphite, Epoxy, Epon 828, Carbon, Fiber, Composites.

1. INTRODUCTION

Textile structural composites form a new group in the family of fiber reinforced composite materials, and attracted more and more attentions for basic structure applications. Among textile structural composites, the three dimensional (3-D) braided composites are especially prominent due to two advantages, namely the three dimensionally integrated structure and the ease for forming complex structural shapes. The fully integrated structure resists delamination, so that the toughness of the material is greatly increased. The capability of braiding complex shape enables preforms being fabricated to near net shapes of the final products. The 3-D braided composites are now used as engineering materials mainly for aeroplane and aerospace structures and show a prominent future for broader range of applications.

Superior mechanical properties of three dimensional (3-D) braided composites have led to wider and wider applications of these relatively new materials. Most of the mechanical properties of the 3-D braided composites have been the subject of many publications [1-9]. Nothing has been found in the literature about torsional properties, which is the subject of this paper, of the 3-D braided composites.

2. SPECIMEN PREPARATION

There are now mainly two groups of 3-D braiding techniques, namely the 2-step and 4-step processes. In the 4-step process, braiding is accomplished with at least four distinct motions in each machine cycle, while in the 2-step process, each machine cycle includes two distinct motions. Although both processes have the common advantages of the 3-D braiding technology, structures produced from them are not same [10]. In this paper, the 4-step 3-D braiding process is used to produce the preforms for the test specimens.

The schematic drawing of the fully automated 4-step braiding machine built in Mars Mission laboratory at NCSU is given in Figure (1). This machine was used to produce the preforms used in this work. The braiding or Cartesian motions are controlled by a microcomputer both in action sequence and speed. The shape of the braid cross-section is determined by the arrangement of the carriers on the machine bed. The fiber carriers can supply yarn continuously and have a rewinding length of approximately five feet. There are many different braiding patterns of the 4-step process, the one selected to braid the test specimens is the most widely used 1x1 pattern. Figure (2) shows a repeat unit inside the 1x1 4-step structure, which reveals the yarn paths and interlacing.

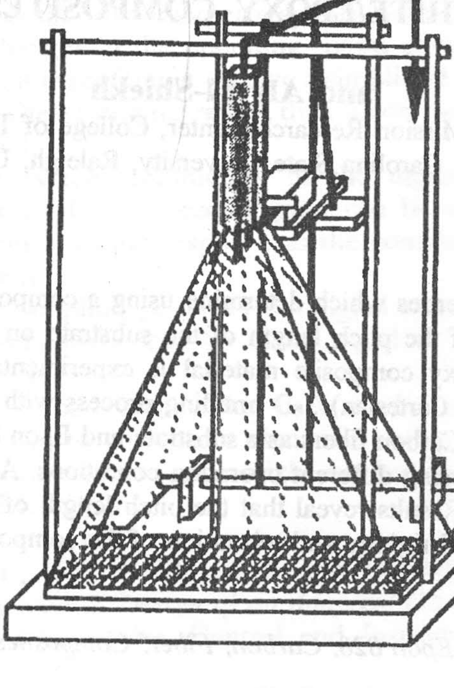

Figure 1. Schematic drawing of the 3-D braiding machine.

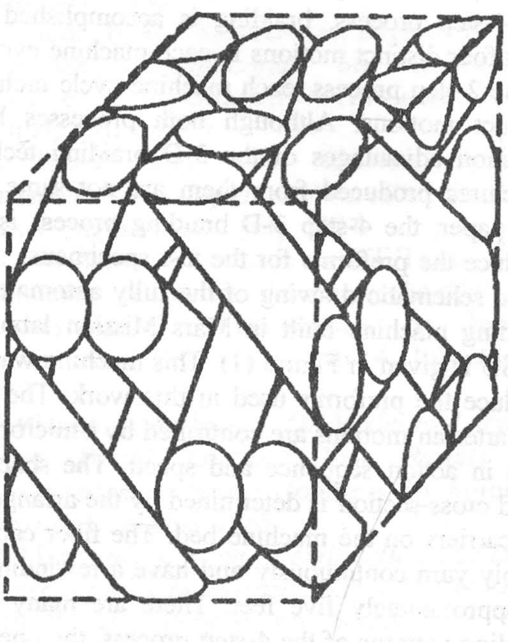

Figure 2. A repeat unit of the 4-step braid.

Shown in Figure (3) is the machine arrangement an the braiding sequence for the specimens which ar rectangular slabs. The carriers inside the marked fram in Figure (3) constitute the main part of th arrangement. It is the shape of the main part tha determines the shape of the preform cross section. A braid can be defined by the number of tows at eac side of the main part. When a main part is fixed, th number of tows in the fabric and their braiding path are also determined.

The test specimens were made using 12k Celion G3 500 graphite fiber as reinforcement and Epon 828 resi with curing agent Jeffamine T403 as matrix. The siz of the specimens is given in Figure (4) which is finally determined by the mold and the preforms were braide to approximately that size, so that no cut wa conducted along the width and the thickness. The specimens were produced with different pitch lengths 7, 12, and 14 mm. The braided graphite preforms were then impregnated with epoxy resin using vacuum impregnation technique.

3. TORSIONAL TEST

A home made torsional at the Textile Department, Alexandria University, was used to conduct the tests. Figure (5) shows a schematic drawing of this tester. The torque is applied through the rotatable jaw and the corresponding angle of twist is measured on the protractor. Precautions were taken to make tested sample concentric with the applied torque.

4. RESULTS AND DISCUSSION

Apparently, braided composites consist of four distinct regions. Each region has it own composition and, consequently, its own behavior under loads which depends on loading conditions. These regions are as follows;

i) Fibrous structure "tows" region,
ii) Deep resin regions which occupy air gaps inside the unit cell,
iii) Shallow resin regions which lie in between tow crossings and over knees of tows on the surface, and
iv) Interfacial regions in which resin molecules adhere to tows. Behavior of this region depends on fiber, resin, additives, and the curing cycle.

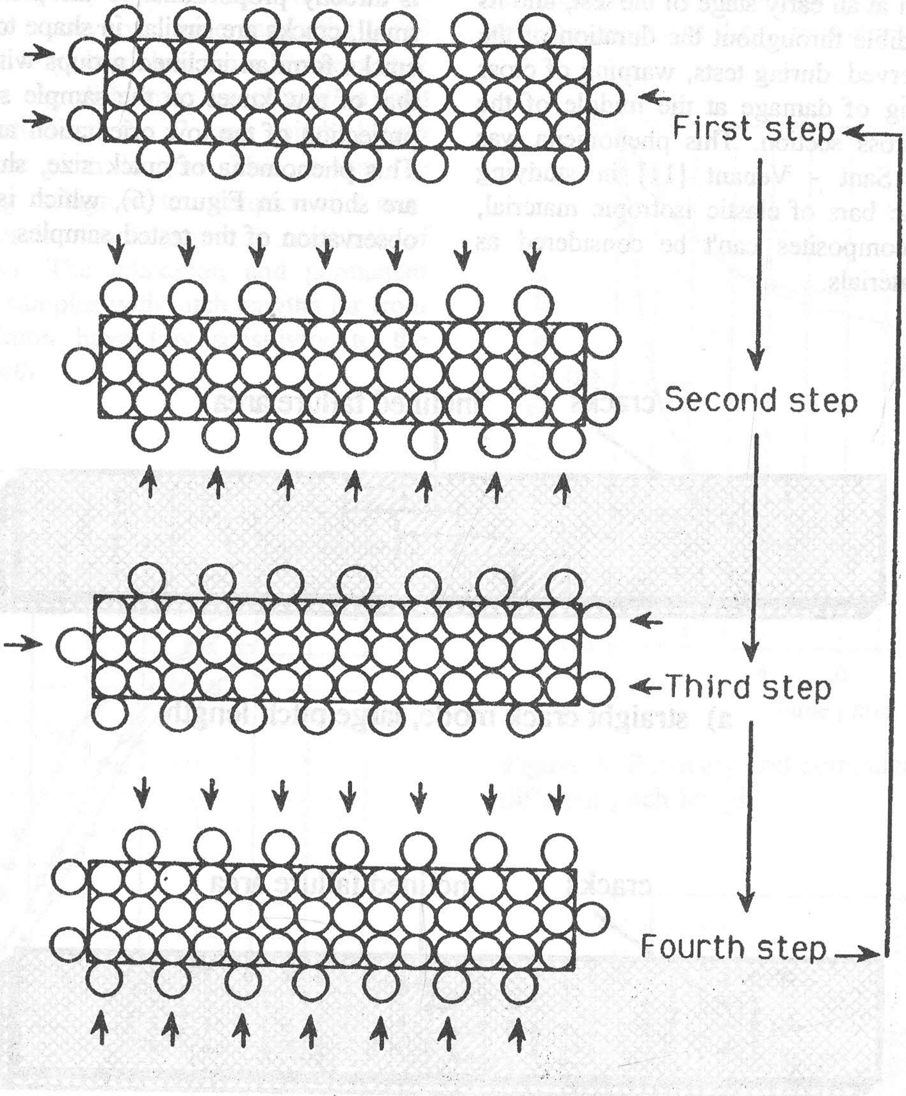

Figure 3. The braiding pattern.

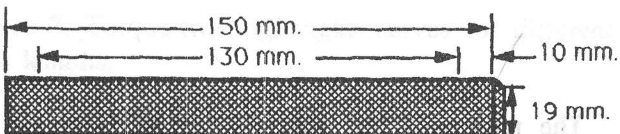

Figure 4. Specimen size.

All of these four regions in size and behavior depend on the fiber volume fraction which, in turn, depends on the pitch length.

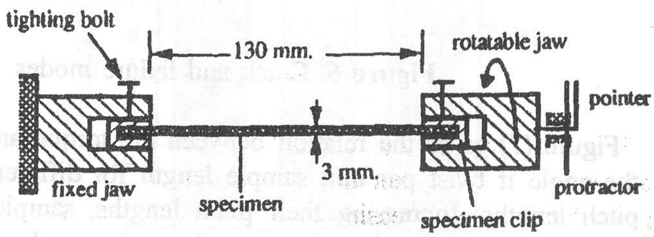

Figure 5. Schematic drawing of the torsional tester.

Visual observation of the specimens revealed that damage propagated during the test through intermittent cracking and debonding of the matrix over tow kness. This damage started at an early stage of the test, and its occurrence was audible throughout the duration of the tests. It is also observed, during tests, warping of cross sections and starting of damage at the middle of the long side of the cross section. This phenomena was observed also by Sant - Venant [11] in studying stresses in prismatic bars of elastic isotropic material, although braided composites can't be considered as elastic isotropic materials.

Because cracks take place over tow knees, crack size is directly proportional to the pitch length. Becoming small, cracks are similar in shape to scales. In all cases, cracks form an inclined groups with the same angle as that of tow knees on the sample surface, which is the projection of the tow orientation angle on this surface. This phenomena of crack size, shape, and inclination are shown in Figure (6), which is obtained by visual observation of the tested samples.

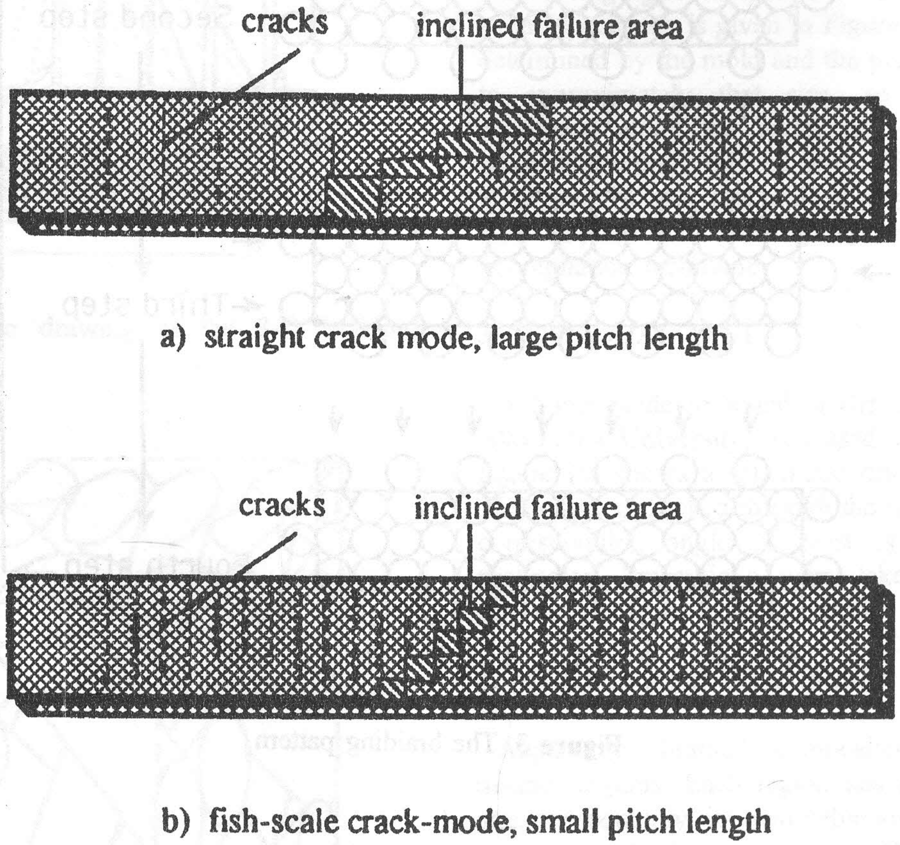

Figure 6. Crack and failure modes.

Figure (7) gives the relation between the torque and the angle if twist per unit sample length for different pitch lengths. Increasing their pitch lengths, samples become weak to resist torque at the same angle of twist, their yield points move toward lower torque and lower angle of twist.

The reason of that may be the decrease of fiber volume fraction through the application of the mixture theory.

When torque is removed, the tested sample shows instantaneous recovery "IR", time-dependent recovery "TR", and keeps permanent deformation "PD". Each of them is affected by the pitch length in a way or another. Figure (9) represents the relation between time-dependent recovery ratio and time for different pitch lengths. The recovery ratio can be defined as the ratio between the recovery angle and the total time-dependent recovery. It is clear from Figures (8) & (9) that there is a big difference in relaxation and permanent deformation of the 7 mm. pitch length relative to the other pitch lengths. This is may be because the resoring is high in the samples of 7 mm. pitch length as a result of near jamming condition of the fibrous skeleton. The relaxation and permanent deformation for the samples with pitch lengths far from the jamming condition have low sensitivity to the change in pitch length.

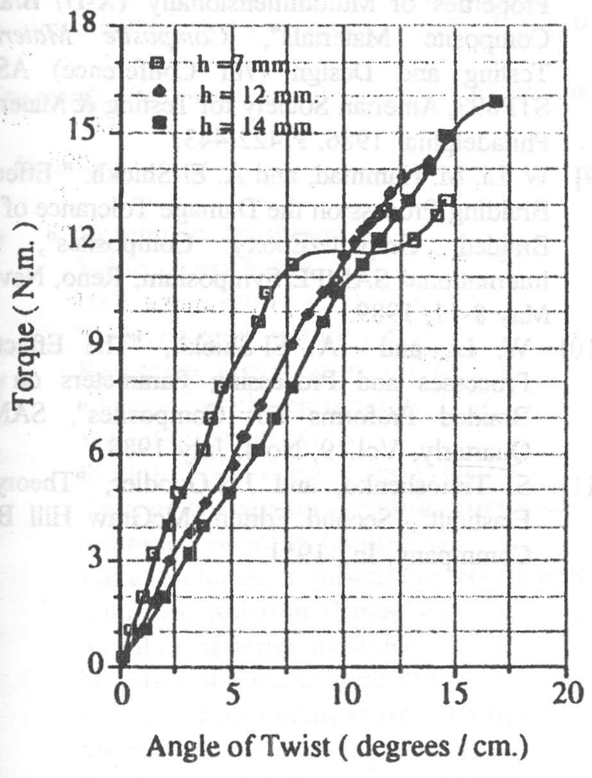

Figure 7. Torque-twisting angke curves for different pitch lengths.

5. CONCLUSIONS

In this paper, the effect of the pitch length of the substrate on the torsional rigidity and relaxation of 3-D braided Graphite / Epoxy composite material is experimentally assessed. Damages introduced are studied and reported. Results reveal that the pitch length of the braided substrate plays a significant role in affecting the torsional rigidity, relaxation and damage pattern of the composite material.

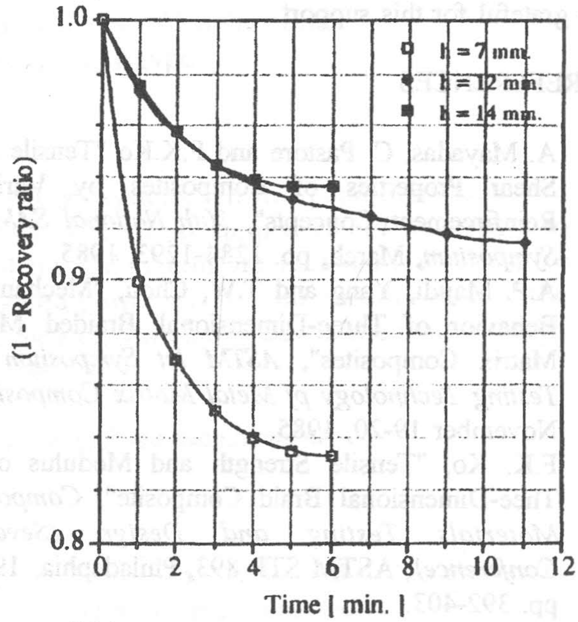

Figure 8. Recovery and permanent deformation for different pitch length.

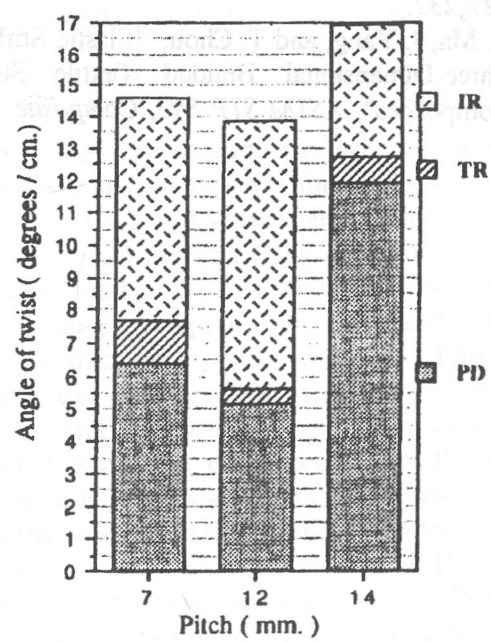

Figure 9. Time-dependent recovery against time for different pitch lengths.

6. *Acknowledgment*

This work is partially supported by NASA Head quarters under Grant No. NAGW-1331, and the authors are grateful for this support.

7. REFERENCES

[1] A. Mayadas, C. Pastore and F.K.Ko "Tensile and Shear Properties of Composites by Various Reinfircement Concepts", *30th National SAMPE Symposium*, March, pp. 1284-1293, 1985.

[2] A.P. Majidi, Yang and T.W. Chou, "Mechanical Behavior of Three-Dimensional Braided Metal Matrix Composites", *ASTM Ist Symposium on Testing Technology pf Metal Matrix Composites*, November 19-20, 1985.

[3] F.K. Ko, "Tensile Strength and Modulus of a Thee-Dimensional Braid Composite", *Composite Materials Testing and Design (Seventh Conference)*, ASTM STP 893, Philadephia, 1986, pp. 392-403.

[4] S. Yau T.W Chou, and F. K. Ko, "Flexural and Axial Compressive Failures of Three-dimensionally Braided Composite-I-beams", *Composites*, Volume 17, No3, July, 1986, pp. 227-232.

[5] C. Ma, J. Yang, and T. Chou, "Elastic Stiffness of Three-Dimensional Braided Textile Structural Composites", *ASTM STP 893, Composite Materials : Testing and Design*, American Society for Testing Materials, Philadelphia, 1986, pp. 404-421.

[6] F.K. Ko, H. Chu, and E. Ying, "Damage Tolerance of 3-D Braided Intermingled Carbon/PEEK Composites", Second Conference on Advanced Composites, Nov., 1986, pp. 75-88.

[7] L.W. Gause, and J. M. Alper, "Structural Propperties of Braided Graphite/Epoxy Composites", *Journal of Composites Technology & Research*, Vol. 9, No. 4, Winter 1987, pp. 141-150.

[8] A.B. Macander, R. M. Crane, and E. T. Jr. Camponeschi, "Fabrication and Mechanical Properties of Multidimensionally (X-D) Braided Composite Materials", *Composite Materials*; Testing and Design (7th Conference) ASTM STP893, Amerian Society for Testing & Materials, Philadelphia, 1986, P 422-443.

[9] W. Li, M. Hammad, and A. El-Shiekh, " Effect of Braiding Process on the Damage Tolerance of 3-D Braided Graphite/Epoxy Composites", 34th International SAMPE Symposium, Reno, Nevada, May 8-11, 1989.

[10] W. Li, and A. El-Shiekh, "The Effect of Processes and Processing Parameters on 3-D Braided Preforms For Composites", SAMPE Quarterly, Vol.19, No.4, July 1988.

[11] S. Timoshenko, and J.N.Goodier, "Theory of Elasticitt", Second Editon, McGraw Hill Book Commpany, In., 1951.