EFFECT OF ORIENTATION OF GLASS FIBER MAT-EPOXY COMPOSITE ON MECHANICAL PROPERTIES

A. K. M. Masud[1] , Md. Kamal Miah[2] , Abdullah-Al-Khaled[3] and Farhana Abedin[4]
[1,2,3,4]Department of Industrial and Production Engineering,Bangladesh University of Engineering and Technology (BUET),Dhaka

ABSTRACT

Fiber reinforced plastic composites are drawing attention in the field of material research due to their light weight, but their development have been hindered by their inferior mechanical properties. Thus extensive research is being carried out to improve their mechanical properties. In this research, an experimental investigation has been conducted by incorporating Chopped Strand Mat and Woven Roving Mat of glass fiber into epoxy matrix. Here different orientations of the mats are considered in order to improve the mechanical properties of glass fiber reinforced composite. A die is manufactured to accommodate different orientation of the glass fiber mats. Specimens are cut from the molded composite plates according to the ASTM specifications. Tensile test is carried out in order to investigate the effect of orientation of glass fiber mats on mechanical properties of the composites. Tensile strength, Young's modulus, Energy absorption and Elongation properties of the composites are analyzed and compared with the properties of the Epoxy resin.

Keywords: Copped Strand Glass Fiber Mat, Epoxy and Energy Absorption.

1. INTRODUCTION

Fiber reinforced composite structure have been used in airspace industries, automotive industries, marine, civil engineering, sporting goods, medical equipments, prosthetic devices for their light weight and favorable mechanical properties. Fiber reinforced composites exhibit high strength, high stiffness, unique design capabilities and easy to fabricate.

Reinforcement of plastics by glass fiber is one of the research areas to the material researchers over the last decades. Different combination of plastics and glass fibers in several orientations have been employed for the glass fiber reinforced composites [1, 2]. The key concern of these researches is to improve the mechanical properties and to evaluate their fracture mechanism in order to use the composites in several structures effectively [3-11].

The effect of orientation of the fiber on the mechanical properties is an important characteristic of the fiber reinforced plastic composites. The properties of the composites in the direction of fiber orientation and transverse to it are significantly different [13, 14]. The mechanical properties are much higher when stress is applied in the direction of fiber orientation than when it is applied transverse to it.

Recently, glass fiber reinforced plastics are produced by laminate structures. It is found that most of the researchers provided experimentations on 0^0, 90^0, $\pm45^0$ laminate structures in only two-dimensional orientation of the fibers [15]. Thus mechanical properties are modified only in the two dimensions. In this research, attempts are taken to provide three-dimensional orientations of the fibers into the matrix experimentally. Here chopped strand mat and woven roving mat of glass fiber are taken as reinforcement for the epoxy matrix. Longitudinal and vertical orientations of the mats have been considered to improve the mechanical properties.

2. EXPERIMENTATION

2.1 Materials used

Commercially available discontinuous chopped strand mats and continuous woven roving mats of E-glass fiber are used as reinforcing materials to manufacture glass fiber composites. Also commercially available epoxy resin is used as matrix for the composites.

2.2 Description of Die

Figure 1 shows the different components of die used for molding of the composites. The die is consisting of the bottom part, top part, flat rectangular thickness bars and a frame rod. Detailed dimensions of the components of the die are given in Table 1. During the molding process all these components are combined to facilitate the composites fabrication. At first bottom part is placed and the thickness bars are also placed over it in such a way that surrounds the periphery of the bottom part. Thus the surrounded space is remained for composites lay up. The thickness of bars is so designed that would maintain the thickness of the fabricated

Corresponding author: *cat76102@hotmail.com*

composites. Then the rod iron frame is placed over the bottom part in such a way the legs of the frame is inserted into precut corner holes of the bottom part. This frame is used for the purpose of vertical reinforcement and the vertical reinforcement is done by hanging the mats from the frame towards the surface of the bottom part. Detailed description of the vertical orientation of the fibers is clearly demonstrated in following section (Fabrication process). After inserting the fibers and the matrix, the frame is released and the top part is placed over the surrounded thickness bars.

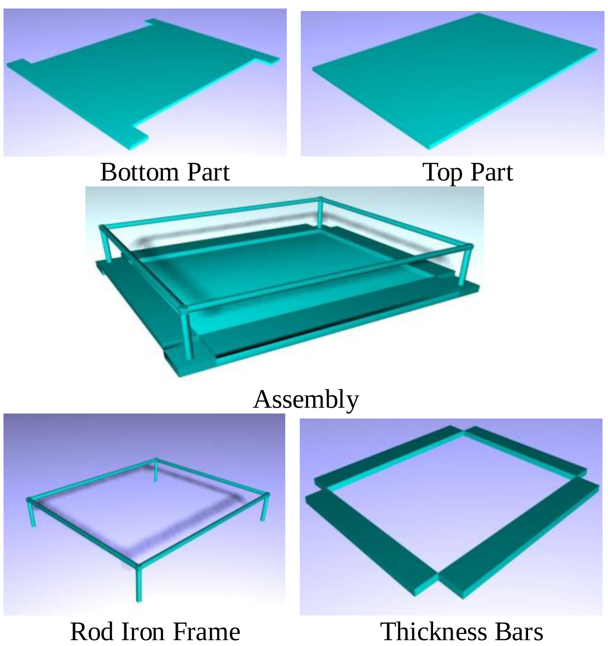

Fig. 1 Components of die and their assembly

Table 1 Dimensions of the parts of Die

Part Name	No	Length mm	Width mm	Thick-ness mm
Bottom part (with 30 mm x 30 mm x 4 flanges)	1	410	410	5
Top part	1	400	400	5
Thickness bars	4	350	30	5
Rod Iron Frame of 10 mm diameter with 25 mm high legs	1	370	370	

2.3 Description of the orientation patterns of reinforcement

With the help of the die four types of composites have been manufactured. Details of the types of composites are described below.

a) Type A: Five longitudinal layers of chopped strand glass fiber mats have been incorporated in the epoxy matrix.
b) Type B: One layer of woven roving mat of glass fiber is placed between two successive layers of chopped strand glass fiber mats. These layers of glass fiber mats have been incorporated sequentially into the epoxy matrix as depicted in figure 2.
c) Type C: Alternate layers of three chopped strand glass fiber mats and two woven roving mats have been incorporated in the epoxy matrix as shown in the figure 2.
d) Type D: Five longitudinal layers and one vertical layer of chopped strand glass fiber mat have been incorporated in the epoxy matrix. Thus the orientation of the chopped strand mats becomes three dimensions. Tensile specimens are cut from the molded plate in such a way that the vertical layer would remain in the middle of the width of the specimen. Figure 2 shows the different positions of the layers of glass fiber mats in above described different types of composites. In order to compare the properties of these composites with the matrix, specimens of pure matrix have also been manufactured.

In each of the composite, five horizontal layers of mats have been incorporated. But, in case of type D, 9 numbers of vertical orientations of glass fiber mats have been incorporated. Adequate spaces have been cut from each of the 5 horizontal layers of mats for incorporating these 9 vertical mats. Thus the volume fraction of fibers is reduced due to the cut open spaces. Then the vertical mats are incorporated through the cut spaces in order to compensate the reduction of volume fraction. It is obvious that some unfilled spaces are remained even after incorporating the vertical mats. It is assumed that the loss of fiber volume fraction due to these remaining spaces are compensated by the portion of vertical mats appeared among the gaps of the horizontal layers. By this way, we maintained constant volume fraction and changed only the orientation of mats.

2.4 Fabrication Process

At first, the bottom part of the die is covered by thin Teflon sheet, and then the thickness bars are placed over the Teflon sheet in the extreme sides of the bottom part leaving a rectangular space for composites molding. The bars are firmly fixed by C clips in such a way that they would not move during the pouring and lay-up of the epoxy resin mix and glass fiber mats respectively. The thickness bars are so design that they could maintain the desired constant thickness of the fabricated composite plates.

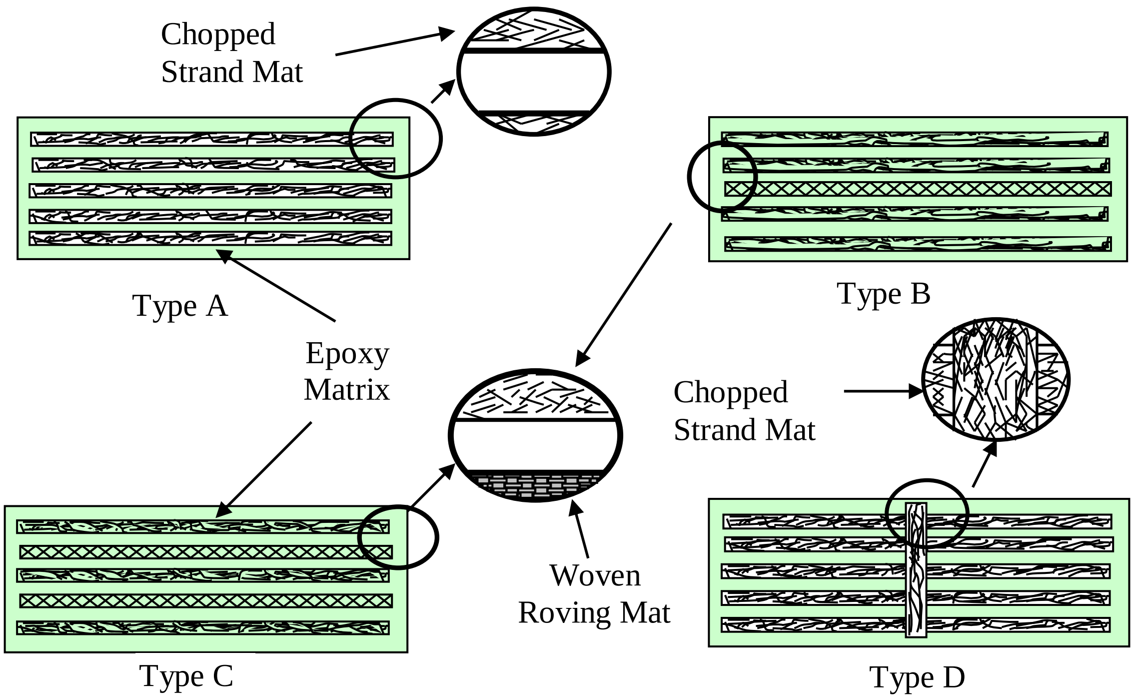

Fig. 2 Schematic illustrations of glass fiber mats in different types of composite.

In case of fabrication of type A, B and C, rectangular pieces of chopped strand mat and woven roving mats of glass fiber are cut in size of the remained space surrounded by the thickness bars. A layer of the epoxy resin mix is incorporated in the surrounded space. The cut rectangular mats are placed over the layer of the epoxy resin mix and rolled over it for complete wet out and for removal of trapped air. Another layer of epoxy resin mix is incorporated over the layer of the mat and then repeated the process similarly till the five layers of glass fiber mats, according to the sequence shown in the figure 2.

In case of fabrication of type D composite, the frame is placed over the bottom part by inserting the legs of the frame into precut holes just after placing the thickness bars over the Teflon sheet. Strips of chopped strand glass fiber mat are cut with two different types of dimensions. 5 mm width strips are cut for vertical orientation and 35 mm width strips are cut for longitudinal orientation. Lengths of the each strip are same as length of the surrounded space. Steel wires are tied over the frame with 35 mm of equal spacing in order to hang the 5 mm strips for vertical orientation. Then the strips are hung over the steel wires by some clips as shown in figure 3. First layer of epoxy resin mix is incorporated over the Teflon sheet through the gaps among the vertical layers. 35 mm strips are then laid up over the resin mix layer of the gaps and rolled over it. Another layer of epoxy resin mix is incorporated over the layer of the mat and then repeated the process similarly till the five layers of glass fiber mats. During the process of incorporating the resin mix the longitudinal and vertical strips are wet out. After curing, the steel wires and the frame are removed from the die and remaining excess burrs are trimmed out.

For all the types of the composites, a top layer of resin mix is incorporated and then covered by a Teflon sheet. A compressive load is applied over the mold after placing the top part of the die on the top of Teflon sheet. This compressive load is remained for 24 hours for complete curing. A post curing is done for 5 hours at a temperature of 100^0 C in an insulated oven.

It can be mentioned here that applied load is constant for each of the cases. Furthermore, same amount of resin has been incorporated in each of the types of composites. Thus the fiber and matrix contents are approximately same for each of the cases. The constant load is applied and the squeezing is restricted by the thickness bars for each of the composites. By this way, it is assumed that constant load and constant squeezing are maintained.

Fig. 3 Strips of 5 mm width hung over the steel wire tied on the frame for Type D composite fabrication

Tensile test specimens are cut as per standard of ASTM D3039 using milling operation. The machined sides and necks of the each specimen are carefully polished to remove possible surface flaws. Ten specimens of the matrix and the composites of each type are prepared for tensile test. Average width and thickness of each type of specimens are measured. Average widths and thicknesses for all the specimens are found as 23.5 ± 0.5 mm and 4.5 ± 0.5 mm respectively.

The fiber content of each type of composites are calculated and found as 21, 20, 20 and 22 volume percentages for type A, B, C and D respectively.

2.5 Tensile Test

Tensile test of each type of specimen are carried out by a computer-interfaced data capturing universal testing machine (Instron model 3369 servo-hydraulic). Crosshead speed of the machine is maintained at 2 mm/min. Ten specimens of each type of composites and matrix are tested by the machine under same condition. Data of the load and displacement are captured from the machine's software and used for calculation.

3. Result and Discussion

Stress-strain curve of each type of composite and matrix are drawn from the captured data. Samples of the stress-strain curves of one specimen of each type of composite and matrix are shown in figure 4.

From the stress-strain diagram it is found that maximum stress of matrix is lowest compared to that of the other types of composite. Maximum stress and strain of type D composite are superior to that of the matrix and the other composites. Type A, B and C exhibit higher maximum stress and lower maximum strain compared to those of the matrix. Here it can be drawn by analyzing the figure 4 and figure 2 that longitudinal orientation of the fiber mats improve the maximum stress considerably and degrade the maximum strain compared to those of the matrix. But the composite having combination of longitudinal and vertical orientations of glass fiber mats (type D), exhibit superior maximum stress and strain compared to those types of composite having longitudinal orientation only. It is also observed that of type D composite is superior to the matrix as well.

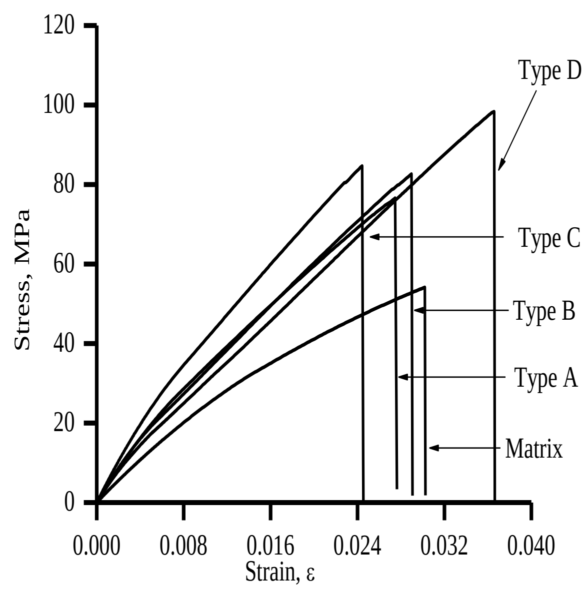

Fig. 4 Stress-strain curves of different types of composite and matrix

Strength, maximum strain, young's modulus and energy absorption properties of all ten specimens of each type of composite and the matrix are calculated. Average values and corresponding standard deviations of the properties are compared in figure 5, 6, and 7.

From figure 5, it is found that strength of type D composite is highest compare to the other types of composite. It can be drawn from figure 5 and figure 2 that vertical orientation of mat has reinforced efficiently in type D composite. On the other hand, type A, B, and C composites exhibit superior strength compare to that of the matrix, because of the reinforcement by the longitudinal orientation of the glass fiber mats. Thus the vertical orientation of glass fiber mat has highest contribution to the strength property.

From the figure 5, it can also be observed that type C composite exhibit highest young's modulus compared to those of the other composites and the matrix as well. It can be analyzed that alternate layer of woven roving mat has highest contribution to the young's modulus. Single layer of woven roving mat in the type B composite hardly improve the young's modulus compared to the other composites.

From figure 6, it is found that strain of the type D composite is highest and type C composite is lowest compared to that of the other composites and the matrix as well. It can be analyzed from the figure 6 that vertical orientation of the glass fiber mat has highest contribution to the strain of the composite. On other hand, alternate layer of woven roving mat has lowest contribution to the strain.

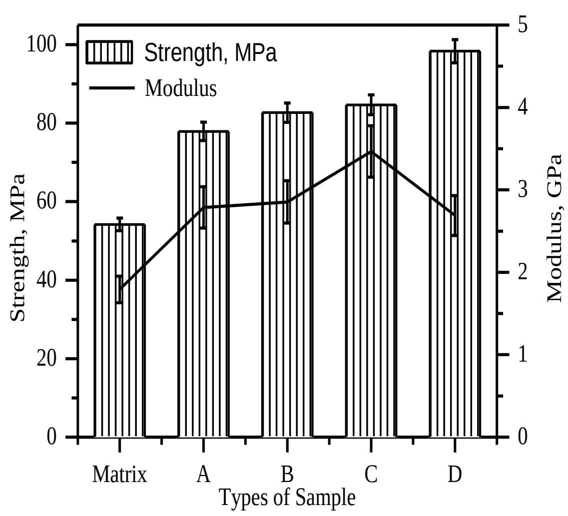

Fig. 5 Comparison of strength and Young's modulus of different types of composite and the matrix

From figure 7, it is found that the vertical orientation of the glass fiber mat has highest contribution to the energy absorption property of type D composite. But alternate of woven roving mat has lowest contribution to the energy absorption property of type C composite that vertical orientation of the glass fiber mat not only reinforced the strength property but also improved the strain and energy absorption properties maintaining Moderate young'smodulus Thus it can be concluded here that the vertical mat greatly influences the mechanical properties.

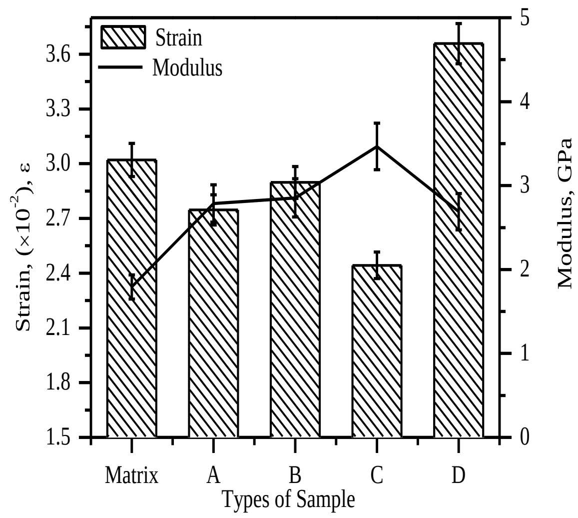

Fig. 6 Comparison of strain and Young's modulus of different types of composite and the matrix

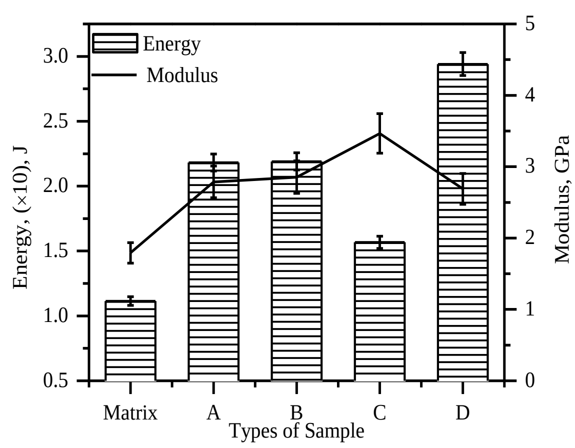

Fig. 7 Comparison of Energy absorption and Young's modulus of different types of composite and the matrix

Type A and type B composites have similar energy absorption property but type C has lower energy absorption property compared to the type A and B. On the other hand, type A and B has similar strain but type C has lower strain compared to the type A and B. From this analysis it can be said that woven roving mat orientated in longitudinal direction in type B composite has little contribution to the strain and energy absorption properties compared to the type A composite. It can also be said that multiple layer of woven roving mat in type

C composite even decrease the strain and energy absorption properties compared to those of the type A composite.

Strength of type B and type C hardly improved compared to that of the type A composite. However young's modulus of type C composite is highest compared to other types of composites.

From above analysis it can be concluded that the vertical orientation of glass fiber mat reinforced the matrix effectively compared to other types of orientation of the composites. On the other hand it can also be concluded that longitudinal orientation of woven roving mat has less effect on the mechanical properties of the composites. Although the woven roving mat consists of continuous long fibers, but the reinforcement by the woven roving mat are found experimentally inferior. The cause behind this kind of behavior is that the poor wetting of the woven roving mat with the high viscous epoxy matrix compared to the porous chopped strand glass fiber mat and epoxy system. High wetting property of glass fiber mats compared to the other mats is mentioned in Ref. [16].

4. Conclusion

In this research fabrication process has successfully been developed to incorporate vertical orientation of chopped strand glass fiber mat. The mechanical properties of the composites having vertical orientation exhibit significant improvement compared to the composites of longitudinal orientation of the mats. From the experimental results it is found that the strength and the energy absorption properties of the composite having vertical orientation improved 81.46%, and 150.96% respectively compared to those of the matrix system.

5. REFERENCES

1. *Corum J., Ruggles M., Battiste R. L., Simpson W. A., McCoy H. E. and Weitsman Y. J.,1996, "Durability of composites in automotive structural applications.", Annual Automotive Technology Development Customers Coordination Meeting, Vol. II: Automotive R&D Poster Session, pp. 313-327.*
2. *Karger-Kocsis, J. and Fejes-Kozma Zs., 1994, "Damage zone development and failure sequence in glass fiber mat-reinforced polypropylene under static loading conditions.", Mechanics of Composite Materials, 20(l), p13 .*
3. *Ren W. and Brinkman C. R., January 1998, "Creep and creep rupture behavior of a continuous strand, swirl mat reinforced polymer composite in automotive environments.", Proceedings of International Composites Expo '98, Nashville, TN., Session 21-E.*
4. *Corum J. M. et al., November 1999, "Durability-based design criteria for a chopped-glass-fiber automotive structural composite", ORNL/TM-1999/182, Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory.*
5. *Corum J. M. et al., February 1998, Durability- design criteria for an automotive structural Composite: part 2. Background data and models", ORNL-693 1, Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory.*
6. *Ren- W., 2001, "Time-dependent deformation modeling for a chopped-glass-fiber composite for automotive durability design criteria", Composites science and Technology.*
7. *Farley, G. L., 1986, "Effect of Specimen Geometry on the Energy Absorption Capability of Composite Materials", J. Comp. Mat., 20, pp.390-400.*
8. *Majzoobi, G.H., and Sainee, F., 2005, "A tensile impact apparatus for characterization of fibrous composites at high strain rates" , Journal of Material Processing Technology, Vol.162-163, pp. 76-82.*
9. *Pardo, S., Baptise, D., and Fitoussi, J. , 2002, "Tensile dynamic behavior of a quasi- unidirectional E-Glass polyester composite", Composites Science and Technology, Vol.62, pp. 579-584.*
10. *Farley, G. L., 1987, "Energy Absorption in Composite Materials for Crashworthy Structures", Proc. Of ICCM6, Elsevier Science Publishers, London, pp. 3.57-3.66.*
11. *Ramakrishna, S., H. Hamada, and D. Hull. "Impacts and Dynamic Fracture of Polymers and Composites" , (ESIS10), Mechanical Engineering Publications, London, pp. 453-464.*
12. *Heinz, D., Ritcher, B. and Weber, S., 2000, "Application of Advanced Materials for Ship Construction: Experience and Problems", Materials and Corrosion 51, pp. 407–412.*
13. *J. Gao and Y. J. Weitsman, July 1998, "The Tensile Mechanical Properties and Failure Behavior of Composite", MAE598-2.0-CM, The University of Tennessee.*
14. *J. M. Corum, R. L. Battiste, W. Ren, and M. B. Ruggles, November 1999, "Durability-Based Design Criteria for a Chopped-Glass-Fiber Automotive Structural Composite", ORNL- TM-19991182, Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory.*
15. *R. Talreja, July 1995, "Fatigue of Composite Materials", in Durability of Polymer Matrix Composites for Automotive Structural Applications: A State-of-the-Art Review", ORNL-6869, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory.*
16. *Michael G. Bader, Leif A. Carlsson, Carl H. Zweben, John W. Gillespie, and Wilburn Smith, 1989, "Delaware Composites Design Encyclopedia: Processing and Fabriactaion Technology, Volume III" CRC Press, pp. 106-107.*