Development and Charecterization of High Performance Reinforced Carbon-Fiber and Glass-Fiber Composites

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Abstract

Carbon fiber composites are becoming widely adopted in the transportation, sporting goods and wind energy sectors, among others. This is because carbon-fiber composites weigh about one-fifth as much as steel, but can be comparable or better in terms of stiffness and strength, depending on fiber grade and orientation. In addition, carbon fibers show good resistance to creep and good compatibility with epoxy matrix. However, the main drawbacks of carbon fiber composites for industrial use are rather susceptible to stress concentration and impact damage due to the brittleness of carbon fiber. The other major factor that is prohibiting the use of carbon fiber in common use is the high price.

The work presented in this paper investigates the experimental study of tensile properties and flexural properties of glass fiber and carbon fiber laminated composite materials. Behavior of laminated composites under tensile and flexural loading is studied. The test specimens are fabricated according to ASTM standards by vacuum bag molding technique with Reinforcement and matrix in the ratio of 70:30.

***Keywords** – carbon fiber, Glass fiber, Hybrid Laminate, Epoxy Matrix, Tensile Test, Bending Test.*

1. Introduction

Composite materials are new generation materials developed to meet the demands of rapid growth of technological changes of the industry. Composite materials or composites are engineering materials made from two or more constituent materials that remain separate and distinct on macroscopic level while forming a single component.

A composite material is defined as a structural material created synthetically or artificially by combining two or more materials having dissimilar characteristic. One constituent is called matrix phase and other is called reinforcing phase. Reinforcing phase is embedded in the matrix to give desired characteristic.

Matrix materials surround and support the reinforcement materials by maintaining their relative positions. Most composites have been created to improve combinations of mechanical characteristics such as stiffness, toughness, ambient and high temperature strength, wear resistance and aesthetic properties.

Reinforcement is the load bearing material which provides additional properties like wear resistance, corrosion resistance, impact strength, lubricating property, damping properties to the composite. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties.

Since early 1960s, there has been an increasing demand for materials that are stiffer and stronger yet lighter in fields such as aerospace, energy and civil construction. By choosing an appropriate combination of reinforcement and matrix material, manufactures can produce properties that exactly fit the requirement for a particular structure for a particular purpose. Composite material systems result in a performance unattainable by the individual constituents and they offer relatively greater advantages of flexible design. For most of the efficient design involving an aerospace structure, an automobile, a boat or an electric motor; we can make a composite material that meets the need.

Glass fiber reinforced composite materials have been in use since the 1940s. Glass fiber reinforced materials are very light and strong materials, although their stiffness is not very high.

Glass fibre reinforced composite material was developed to meet the requirements of the industry for high-strength materials with low weight. The advantages of Glass fibre Reinforced Polymer (GFRP) material include savings in weight, improvement in strength and decreased cost of material and fabrication. Glass fibre reinforced composites have been used for engineering applications, and various types of glass fibres are used as reinforcements. E -glass fibres are widely used as they have special characteristics such as high strength to weight ratio, good dimensional stability, good resistance to heat, cold, moisture, and corrosion, and good electrical insulation properties. The concept of incorporating a strong fibre or whiskers into a tough or ductile matrix yields a very high strength to the composite as they carry load [1–4].

Carbon fibers have been considered as very important reinforcements due to its high specific strength, specific modulus, low expansion coefficient and good self lubricant properties. Carbon fiber reinforced polymer composite (CFRP) laminates are attractive for many applications in the aerospace industry especially as aircraft structural components due to their superior properties [5-9].

II. Overview of Vacuum bag moulding process

Vacuum bagging techniques have been developed for fabricating a variety of components but mainly for complex shapes, double contours and relatively large components. The technique is employed either to consolidate a wet layup or a Prepreg layup during cure. The process is principally suited for molding low cost components too large and/or complex to be pressurized by other means. This is basically an extension of the wet lay-up process where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by flexible polyethylene sealed bag under which a vacuum is drawn, hence applying an even pressure up to 1 atmosphere (14.7 psi/101 kPa) to the laminate in the mould to consolidate it. A more advanced form of vacuum bagging places a release film over the laminate, followed by a bleeder ply of fiberglass cloth, non-woven nylon or polyester cloth. That absorbs excess resin from the laminate. A breather ply of a non-woven fabric is placed over the bleeder ply, and the vacuum bag is mounted over the entire assembly. Pulling a vacuum from within the bag & the compression under the vacuum helps to eliminate voids and force excess resin from the laminate during curing. The addition of pressure further results in high fiber concentration and provides better adhesion between layers of sandwich construction. To get the optimal properties out of parts made by this process, laminate must be cured by a combination of heat, pressure, and or vacuum. The assembly can then be heated in an oven, as in the case when using prepregs, to promote flow and cure of the resin [10-13].

Fig 1 illustrates a cross section of a simple vacuum bag layup with the constituent parts and their functions.

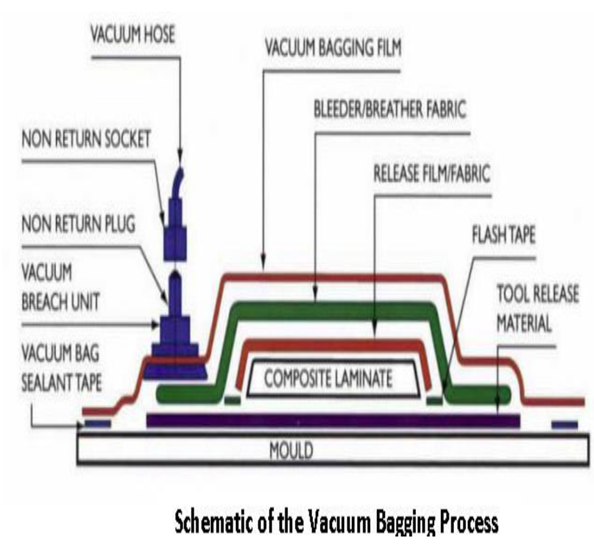


Fig 1 Schematic of the vacuum bagging process

III. Material Testing

3.1 Tensile or Tension test:

A tensile test, also known as tension test, is probably the most fundamental type of mechanical test you can perform on material. Tensile tests are simple, relatively inexpensive, and fully standardized. By pulling on something, you will very quickly determine how the material will react to forces being applied in tension. As the material is being pulled, you will find its strength along with how much it will elongate.

Tensile properties indicate how the material will react to forces being applied in tension. A tensile test is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of the specimen over some distance. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit and reduction in area, tensile strength, yield point, yield strength and other tensile properties.

The main product of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Since both the engineering stress and the engineering strain are obtained by dividing the load and elongation by constant values (specimen geometry information), the load-elongation curve will have the same shape as the engineering stress-strain curve. The stress-strain curve relates the applied stress to the resulting strain and each material has its own unique stress-strain curve. A typical engineering stress-strain curve is shown below. If the true stress, based on the actual cross-sectional area of the specimen, is used, it is found that the stress-strain curve increases continuously up to fracture.

A. Tensile test of carbon and glass fiber hybrid laminates:

The test was conducted on samples of each 2mm, 3mm and 4mm thickness as shown in Fig 2 prepared in accordance to ASTM Standards. The data measured from the mechanical testing was used to calculate the elastic properties and strength of the laminates. Tensile strength, yield stress, peak load, load at break, load at yield, Young's modulus and percentage of elongation were determined and were tabulated as shown in Table 1

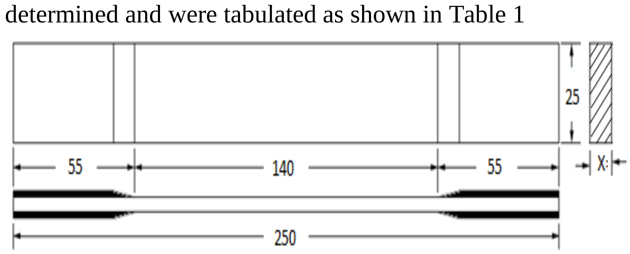


Fig 2 Tensile test specimen (X=2, 3, 4 mm)

Table-1

Specimen no.	Thickness (mm)	Tensile strength (N/mm^2)	Yield stress (N/mm^2)	Peak Load (kN)	Load at break (kN)	Load at Yield (kN)	% elongation
1.	2	455.84	400.22	26.88	26.88	23.60	06.68
2.	2	447.35	410.07	26.40	26.40	24.20	05.94
3.	2	477.77	429.04	28.24	28.24	25.36	12.04
4.	3	331.61	305.00	26.92	26.92	24.76	13.00
5.	3	335.58	297.97	27.48	27.48	24.40	10.54
6.	3	355.83	320.39	29.32	29.32	26.40	10.96
7	4	407.37	365.05	44.28	44.28	39.68	10.74
8	4	430.80	391.78	45.48	45.48	41.36	07.60
9	4	376.44	355.73	40.44	40.44	38.00	11.34

Elastic Properties and Strength of the Laminates

B. Tensile test of Glass fibre laminates

The test was conducted on 2 mm, 3 mm and 4 mm glass fiber laminates. The data measured from the mechanical testing was used to calculate the elastic properties and strength of the laminates. Tensile strength, yield stress, peak load, load at break, Load at Yield, Young's modulus and percentage of elongation were determined. The table-2 shows the values of these properties exhibited by the different specimens of 2 mm, 3 mm and 4 mm respectively.

Specimen no.	Thickness (mm)	Tensile strength (N/mm^2)	Yield stress (N/mm^2)	Peak Load (KN)	Load at break (KN)	Load at yield (KN)	% Elongation
1	2	364.56	306.72	24.20	20.92	20.36	4.26
2	3	429.00	335.59	34.72	34.72	27.16	6.04
3	4	383.33	360.45	43.16	46.54	34.52	27.60

Tensile Properties of Glass Fibre Laminates

3.2 Bending or Flexural test

In engineering mechanics, flexure or bending characterizes the behavior of a slender structural element subjected to an external load applied perpendicularly to a longitudinal axis of the element.
A flexure test produces tensile stress in the convex side of the specimen and compression stress in the concave side. This creates an area of shear stress along the midline. To ensure the primary failure comes from tensile or compression stress the shear stress must be minimized. This is done by controlling the span to depth ratio; the length of the outer span divided by the height (depth) of the specimen.

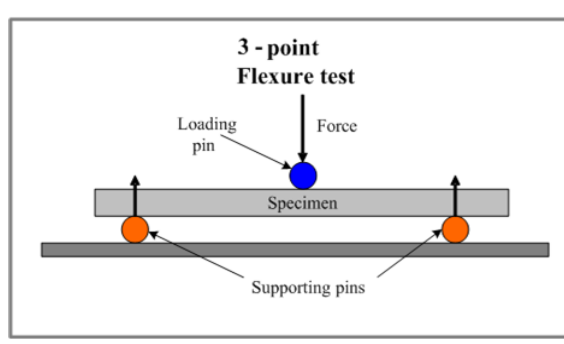


Fig 3 Schematic of Bending test

A. Bending procedure

- Measure the dimensions of the specimen.
- Check the limit of the linear region of the aluminium beam (with no strain gage).
- Switch on the computer and Instron universal test machine and run the associated software.
- Prepare the Wheatstone circuit and connect it to the cables of strain gages which are in turn connected to defined slots of the equipment.
- Use the digital micrometer to record data sample. It must take 10 data samples per unit second. Adjust the associated Instron program with displacement controlled equipment.
- Set the Maximum allowed displacement of the specimen to be 2 mm. After 2 mm it is in plastic region.
- Adjust the software to take 10 Force data per second.
- Run the experiment.

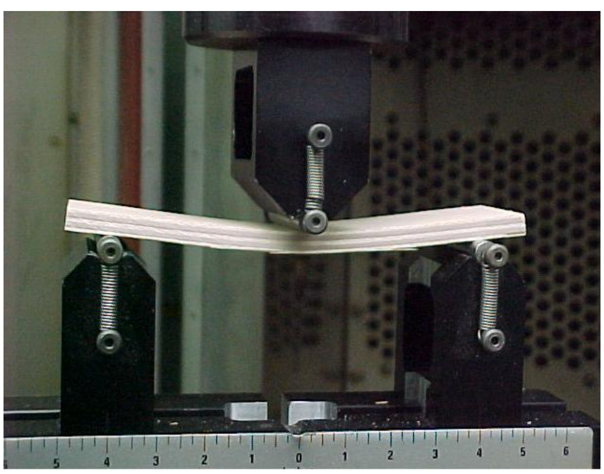


Fig 4 Bending Test Setup

3.3 Bending test of Carbon and Glass fiber hybrid laminates:

The test was conducted on 2mm, 3mm and 4mm Carbon and glass fiber hybrid laminates. The data measured from the mechanical testing was used to calculate the maximum load the specimens can sustain.

The table-3 gives the values of maximum load sustained by the different specimens during bending test.

Table-3

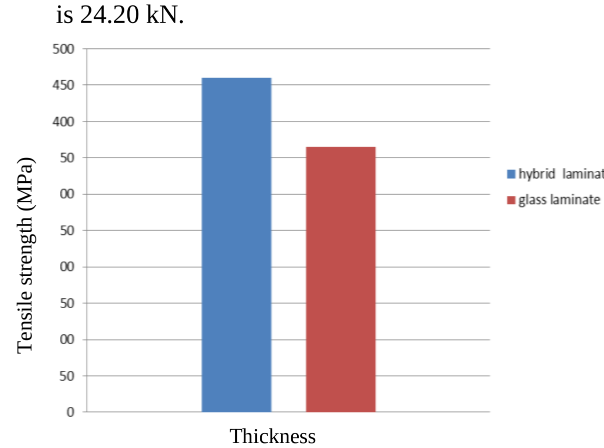
Specimen no.	Thickness (mm)	Maximum Load (N)	Average maximum load (N)
1.	2	654.7	
2.	2	611.0	749.33
3.	2	982.3	
4.	3	982.1	
5.	3	1003.7	978.86
6.	3	950.8	
7.	4	1818.9	
8.	4	1934.9	1869.0
9.	4	1853.2	

Force Date for Bending Test

IV. Results and Discussions

4.1 Comparison of 2mm Carbon fibre and Glass fibre hybrid laminates and Glass fibre laminates

- The average tensile strength of the 2mm hybrid laminate is 460.32 MPa and that of the glass fibre laminate of 2mm thickness is 364.56 MPa.
- The average % elongation of the hybrid laminate is 8.22% and that of the glass fibre laminate is 4.26%.
- The peak load of the 2mm thickness hybrid laminate is 27.173 kN and the glass fibre laminate is 24.20 kN.



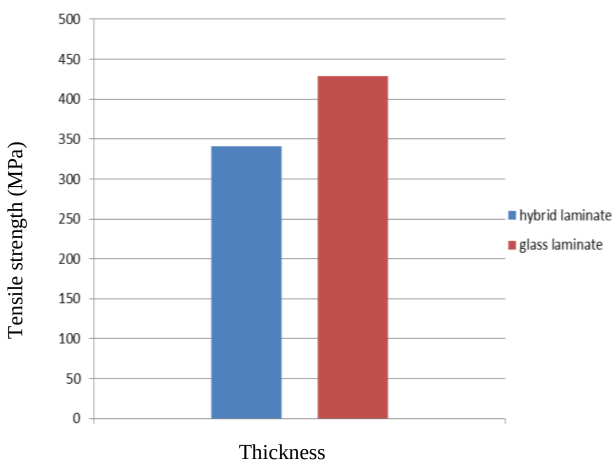
Graph 4.1: Comparison of tensile strengths of carbon fiber and glass fiber hybrid laminates and glass fiber laminates (2mm thickness).

From the graph 4.1, it is clear that the carbon and glass fibre hybrid laminates exhibit more tensile strength when compared to the glass fibre laminates of 2mm thickness.

4.2 Comparison of 3mm carbon fiber and glass fiber hybrid laminates and glass fiber laminates

The average tensile strength of the 3mm hybrid laminate is 341.006Mpa and that of the glass fiber laminate of 3mm thickness is 429.00Mpa.The average % elongation of the hybrid laminate is 11.5% and that of the glass fiber laminate is 6.04%.The peak load of the 3mm thickness hybrid laminate is 27.90 kN and the glass fiber laminate is 43.16 kN.

The graph 4.2 shows that the glass fibre laminate of 3mm thickness exhibits more tensile strength when compared to carbon and glass fibre hybrid laminates.

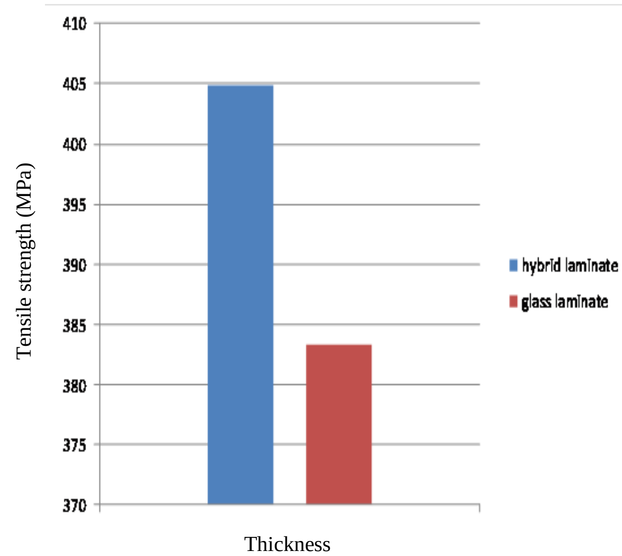


Graph 4.2: Comparison of tensile strengths of carbon fiber and glass fiber hybrid laminates and glass fiber laminates (3mm thickness).

4.3 Comparison of 4mm carbon fibre and glass fibre hybrid laminates and glass fibre laminates

The average tensile strength of the 4mm hybrid laminate is 404.87 MPa and that of the glass fiber laminate of 4mm thickness is 383.33 MPa. The average % elongation of the hybrid laminate is 9.89% and that of the glass fiber laminate is 27.60%.The peak load of the 4mm thickness hybrid laminate is 43.4 kN and the glass fiber laminate is 43.16 kN.

The graph 4.3 shows that the carbon and glass fiber hybrid laminates of 4mm thickness exhibits more tensile strength when compared to glass fiber laminates.

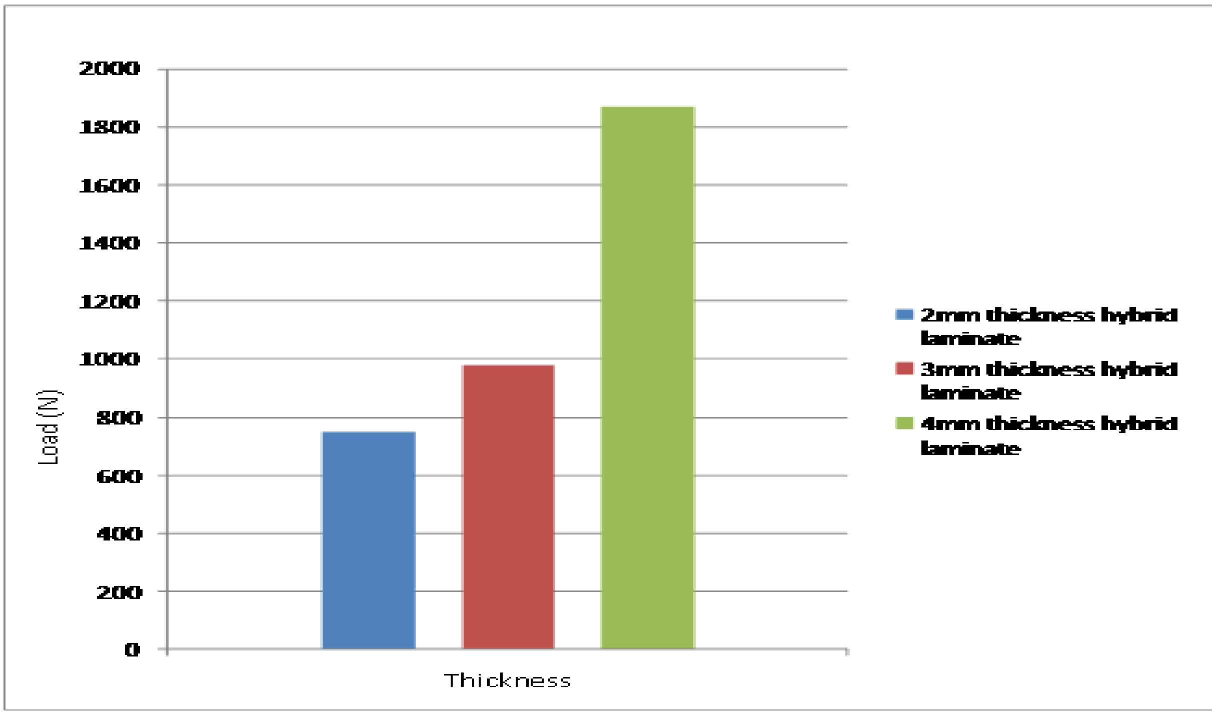


Graph 4.3: Comparison of tensile strengths of carbon fibre and glass fibre hybrid laminates and glass fibre laminates (4mm thickness).

4.4 Bending test of the carbon and glass fiber hybrid laminates

The average maximum load of the 2mm thickness hybrid laminate is 749.33 N. The average maximum load of the 3mm thickness hybrid laminate is 978.86 N. The average maximum load of the 4mm thickness hybrid laminate is 1869.0 N. In case of load v/s displacement graphs for all the three thickness's of 2mm,3mm and 4mm hybrid laminates, the curve increases in a linear fashion up to the upper yielding point and suddenly drops down to the lower yield point and at this point stress remains constant and strain increases to a certain value. Beyond this point the graph suddenly drops down which indicates that there is a sudden reduction in the stress and the specimen has failed.

In the graph 4.4, it is shown that the 4mm thickness hybrid laminate is capable of withstanding the maximum load when compared to the 3mm and 2mm thickness hybrid laminates. It is found out that as the thickness increases the amount of load withstood by the specimens also goes on increasing.



Graph 4.4: Comparison of average maximum load of 2mm, 3mm and 4mm thickness hybrid laminates.

V. Conclusion

By using a simple hand lay-up process, E-glass epoxy and carbon epoxy polymer matrix hybrid composites and glass fiber composites of 2mm, 3mm and 4mm thickness were fabricated. From the composites the test specimens were prepared in accordance with ASTM standards for Tensile and Flexural tests and the following conclusions have been made:

- In case of the tensile test it was found that the carbon and glass fiber hybrid composites exhibited more tensile strength when compared to the glass fiber composites irrespective of their thickness.
- The hybrid composites of carbon fiber and glass fiber exhibited improved tensile and mechanical properties.
- When the comparison was carried out between the hybrid composites of the different thickness, the hybrid composite of 2mm thickness exhibited more tensile strength when compared to the composites of 3mm and 4mm. The reason for this might be the irregular distribution of resin on the individual layers of the 3mm and 4mm thickness hybrid composites.
- In the bending or the flexural test that was carried out the maximum load sustained by the hybrid composites of the varying thickness was in following order 2mm composites < 3mm composites < 4mm composites.

Critical Evaluation of the elastic properties and strength of the laminates of varying thickness have given a clear distinction of the varying properties of Carbon fiber and Glass fiber hybrid laminate composites with that of the glass fiber reinforced laminate.

VI. References

[1] Hull, D. and Clyne, T. W., “An Introduction to Composite Materials”, Cambridge University Press, Great Britain, 1996.

[2] Thomas M. Hermann and James E. Locke National Institute for Aviation Research, Wichita State University and Kyle K. Wetzel, Wetzel Engineering Inc. Fabrication, Testing and analysis of anisotropic Carbon/Glass Hybrid Composites.

Sandia Report, SAND 2005-5748, Unlimited Release, Printed November 2006.

[3] H. Raghavendra Rao, A. Varada Rajulu, G. Ramachandra Reddy and K. Hemachandra Reddy., Tensile Properties and SEM Analysis of Bamboo and Glass Fiber Reinforced Epoxy Hybrid Composites. International Journal of Applied Engineering Research. ISSN 0973-4562 Volume 6, Number 1 (2011) pp. 27–32.

[4] José Ricardo Tarpani, Marcelo Tadeu Milan, Dirceu Spinelli, Waldek Wladimir Bose., Mechanical performance of Carbon-epoxy laminates, Part II: Quasi- static and Fatigue Tensile properties, Journal of Materials Research, Vol. 9, Issue 2, 2006, pp. 121-130.

[5] Donald L Smith and Marvin B Dow., Properties of Graphite/ Toughened Resin Composites. NASA Technical Paper 3102, September 1991.

[6] A. Valenza, V. Fiore G, Di Bella., Specific Mechanical Properties of Glass/Carbon Epoxy Composites for Marine Applications. University of Palermo, Viale delle Scienze, 90128 Palermo, 2002, pp.103-208.

[7] Akira Kuraishi, Stephen W. Tsai, and Julie Wang., Material Characterization of Glass, Carbon and Hybrid-Fiber SCRIMP Panels. Department of Aeronautics and Astronautics Stanford, Stanford University, California. SAND2002-3538, Unlimited Release, Printed December 2002.

[8] Hoo Tien Kuan, Wesley Cantwell and Hazizan Md Akil., The Mechanical Properties of Hybrid Composites Based on Self-Reinforced Polypropylene. Malaysian Polymer Journal, Vol. 4, 2009, Issue-2, pp. 71-80.

[9] Umer Mehmood, S.M.A.Saeed, A.Raza, M.Aziz and M.A.Naseer., Hybridization Effect of Glass and Carbon Fiber on Mechanical Properties of Epoxy Based Composites, Department of Polymer & Process Engineering, University of Engineering and Technology, Lahore, 2007.

[10] Polymer Matrix Composites Materials Usage, Design, and Analysis, Department of Defense Hand Book, Composite Materials Hand Book, Vol. 3, June 2002.

[11] Loren Thomas, Alan Miller, Allan Chan, “Fabrication of complex High performance composite structures at Low cost using Vacuum Bag Moulding”, Proceedings of the International SAMPE Technical Conference (ISTC), 2002.

[12] W.D. Brouwer, E.C.F.C. Van Herpt, M. Labordus, “Vacuum Bag moulding for large structural applications”, Composites Part A: Applied Science and Manufacturing, Vol. 34, Issue 6, 551-558, June 2003.

[13] Jim M. Criss, Jr., Michael A. Meador and Kathy C. Chuang, “New state-of-the art high temperature Vacuum mouldable resins and their composites”, Proceedings of the International SAMPE Technical Conference (ISTC), 2003.

