TENSILE AND FLEXURAL STUDIES ON GLASS - CARBON HYBRID COMPOSITES SUBJECTED TO LOW FREQUENCY CYCLIC LOADING

K. Poyyathappan[#1], G.B.Bhaskar[*2], K. Pazhanivel[#3] N.Venkatesan[*4]
[#] Department of Mechanical Engineering,
Thiruvalluvar College of Engineering and Technology, Vandavasi – 604505, India.
[1] poyyathu@gmail.com
[3] rkvel2003@yahoo.co.in
[*] Department of Mechanical Engineering,
Tagore Engineering College, Chennai – 600127, India.
[2] bhaskarang01@yahoo.com
[4] venkatn01@yahoo.com

Abstract - Glass fiber reinforced polymeric composite (GFRP), Carbon fiber reinforced polymeric composite (CFRP), glass-carbon-glass, carbon-glass-carbon hybrid composite laminates have been prepared by hand layup method. The test specimens have been prepared according to ASTM standard size to carry out the tensile and flexural tests. Six specimens with 0±90° orientation have been prepared for both the tests. The specimens have been subjected to low frequency cyclic load for specific duration prior to the flexural bending analysis. Three point bend method has been adopted to find out the flexural strength and flexural modulus. Flexural strength and modulus have been calculated from the load deflection curve obtained from the tensometer for respective specimens. The results show that the hybrid composites have better flexural properties than the GFRP.

Keywords : GFRP composite, CFRP composite, Glass-Carbon hybrid composite, cyclic load.

I. INTRODUCTION

Composites are attractive materials because of their properties like stiffness and high specific strength which leads to potential application in the area of aerospace, marine and automobile engineering etc. Though these materials have attractive properties, during the processing and service, the composite materials can have some sort of defects like matrix cracking, fiber breakage, fiber pull out, delamination and debonding [1]. Various filling agents are being used to improve the mechanical properties of composite [2, 3]. Friction and wear properties of carbon fabric composites filled with nano alumina and nano silicon nitride were reported by Feng-Hua Su et al [4]. Nano clay particles were used as fillers in soya protein resin based green composite and its characterization were reported [5]. Carbon nano tubes are identified as excellent material to enhance the properties by incorporating it into the composite materials. Improvement of mechanical properties in two phase and three phase composites by adding carbon nano fiber was reported by Yutaka Iwahori et al [6]. Enhanced mechanical and thermo mechanical properties of epoxy composite were observed due to addition of two different functionalized multi-walled carbon nano tubes [7]. Influence of carbon nano tubes on tensile, flexural and impact properties of short fiber reinforced composites was studied and reported by Rahmanian et al [8]. Since the cost of carbon nano tube is relatively much higher some other methods were used to enhance the mechanical properties.

Recently, hybrid composite is being investigated throughout the globe as it has enhanced properties than their mother composites which is relatively cost effective method. The mechanical properties like bending fatigue stiffness and strength degradation have been reported in carbon-glass/epoxy hybrid laminates [9]. An optimal design for the flexural behavior of glass and carbon fiber reinforced polymer hybrid composites was reported by Chensong Dong and Ian J. Davies [10] .The effect of hybrid composite specimen subjected to in-plane tensile and compressive loading was studied and found that the hybrid laminated specimen with higher percentage of steel sustain greater loads irrespective of fiber orientation [11]. An experimental and numerical study has been conducted in order to understand the fracture toughness of glass-carbon (0-90) Fiber Reinforced polymer composites [12]. Glass carbon woven fabrics hybrid composites were investigated on its flexural properties and significant improvement is reported towards the application for light weight load bearing structures [13]. The effect of loading particles on the flexural properties of Multi-layered laminates of bi-directionally woven E-glass fabric/epoxy was studied and found that the composite containing 3 wt% of graphite exhibits the optimum mechanical and wear performances [14]. Uniaxial tension and compression characterization of hybrid carbon nanostructure – glass fiber-epoxy composites were studied by Sam Markkula et al [15]. There are very limited literatures on the investigation of mechanical properties of laminates subjected to low frequency cyclic load within the scope of our literature survey. Hence, we are interested to study the flexural and tensile properties of various combinations of glass and carbon hybrid composites.

In the present work, bidirectional CFRP, GFRP, glass-carbon (G-CRP) and carbon-glass (C-GRP) hybrid laminates have been prepared by hand layup method. The ASTM standard specimens have been induced by low frequency cyclic load. Flexural properties have been studied by three point bend method and a detailed report has been presented on the flexural properties of bidirectional GFRP, CFRP, G-CRP and C-GRP hybrid composites laminates.

Nomenclatures	
P_{max}	maximum load at failure in Newton
$P_{max}L$	Flexural strength
E_F	Flexural modulus

II. Material

The laminate was fabricated by hand lay-up method. Resin/hardener ratio was 100:10 by weight with the following materials.

Type of glass reinforcement: bidirectional mat (600GSM)

Type of carbon reinforcement: bidirectional mat (600GSM)

Matrix (liquid): Epoxy resin(LY 556)

Hardener (liquid): HY 951

Volume fractions of the fibers: 0.4

Four types of laminates were made by changing the layers of glass and carbon fibers and the matrix materials in different combination of mat, such as glass fiber laminate, carbon fiber laminate, carbon-glass fiber laminate, glass-carbon laminate.

III. Experimental Techniques

Bidirectional GFRP, CFRP, carbon-glass (C-GRP) and glass-carbon (G-CRP) hybrid composite laminates of 4mm thickness have been prepared. Epoxy resin LY-556 has been used as the matrix and HY 951 has been used as hardener. The laminates have been made by hand lay-up method and cured in atmospheric room temperature for about 24 hours. Extraordinary care was taken to ensure complete wetting of the fibers and removal of air packets. The thickness of the laminates was maintained approximately 4mm. In CFRP and GFRP laminates all the layers are carbon fiber mat and glass fiber mat respectively. C-GRP (carbon –glass) laminates were made in such a way that the outer mats should be carbon mat and inner should be of alternate mats. Whereas in G-CRP (glass-carbon) laminates the outer layers are glass fiber mats. Six different specimens from each category were cut as per the ASTM standard for tensile and flexural tests and tested accordingly for its tensile strength and flexural strength respectively. The specimens were subjected to cyclic load, to determine the flexural response of the composite in terms of the permanent set of the deflection if any and the amount of energy absorbed during plastic deformation. The number of cycles has been increased by increasing the exposure time such as 20 min, 40 min, 60 min, 80 min and 100 min. Number of cycles per minute was maintained as 105 cycles. The experimental set up designed for making such cyclic load is shown in Fig.1. The maximum deflection of the specimen was fixed as 3mm. ASTM Standard Specimen prepared for flexural and tensile studies are shown in Fig.2.

Fig.1. Experimental set up for making low frequency cyclic load.

Fig.2. ASTM Standard Specimen prepared for Flexural studies (Top) and Tensile Studies (Bottom).

IV. RESULTS AND DISCUSSION

The tensile strength of the sample of CFRP, GFRP, and C-GRP and G-CRP with 0 ± 90^{o} fiber orientation was determined for six samples each and the average value of strength has been taken. The observed tensile strength for the samples has been plotted in the graph as shown in Fig. 3. From this graph, it is observed that the tensile strength of the hybrid composite lies between the Plain CFRP and GFRP. Further it is observed that the position of carbon fiber mat/glass fiber mat has not affected the tensile strength significantly. The sample made with the carbon fiber mat as outer layer and the sample made with glass fiber mat as outer layer have possessed almost equal tensile strength. From this study it is concluded that the inclusion of carbon fiber mat in the glass fiber reinforced polymeric composite significantly enhanced the tensile strength of the composite. Tensile strength and breaking load for the samples prepared are presented in Table1.

TABLE 1
Breaking load and Tensile strength of the samples

Sl.No.	Specimen	Breaking Load(P) N	Tensile Strength N/mm^2
1	Glass	1792	179.2
2	Glass-	2920	292.2
3	Carbon	4000	400
4	Carbon-	2912	291.2

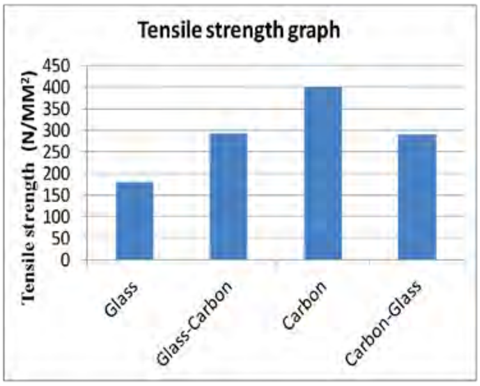

Fig.3. Variation of tensile strength for the fabricated composites with respect to type of laminate.

Fig.4. Load Deflection curve for CFRP before low frequency cyclic load which shows peak load as 1961.4 N.

Usually, common materials like metal will lose its strength and stiffness due to continuous cycle of application of load. Hence, after certain duration the material become useless for the relevant application. The flexural ability of the composite materials in the present investigation has been studied using three point bend method after the respective specimens were subjected to low frequency cyclic load for the duration of 20 min, 40 min, 60 min, 80 min and 100 min in a CAM like arrangement with 105 cycles of rotation per minute.

In this investigation, bidirectional GFRP, CFRP, glass-carbon hybrid and carbon-glass composite have been tested for their flexural strength before and after cyclic load, by a standard 20 KN tensometer. This tensometer gives the maximum load at failure and the load – deflection curve for the particular specimen. The load deflection curve obtained from the tensometer for a CFRP specimen before cyclic load and after exposed to 10500 cycles of loading is shown in Fig.4 and Fig. 5 respectively as samples.

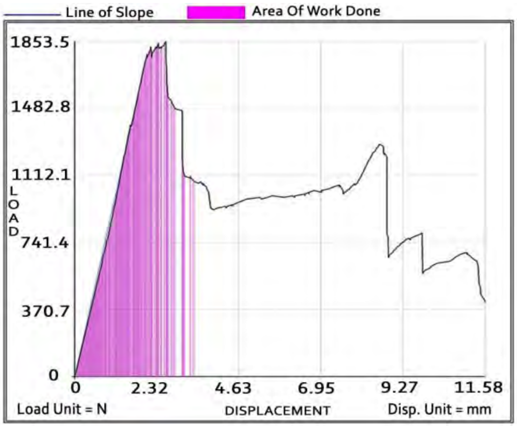

Fig.5. Load Deflection curve for CFRP after 10500 cycles of low frequency cyclic load which shows peak load as 1853.5 N.

By using the following formulae the flexural strength and flexural modulus have been calculated.

Flexural strength = $\frac{3P_{max}L}{2bh^2}$

Flexural modulus $E_F = \frac{mL^3}{4bh^3}$

Where,

P_{max}- maximum load at failure in Newton

L - distance between centers of support in metre

b- width of the specimen in metre

h- thickness of the specimen in metre

m- initial slope of the load-deflection curve

Unlike metallic materials, the flexural strength (within the limits) and the stiffness of polymeric composite increases and decreases frequently with applied cyclic load. Marginal reduction in bending property has been observed with increase in cycle of load. Possibility of defect annihilation can be reason for the observed marginal changes [16]. This calls for careful handling of the polymeric composite for model application. Fracto-graphic analysis revealed fracture by primary de-bonding, with fiber breakage and pull-out in the tensile zone, but a shear fracture of fiber bundles in the compressive zone of the specimen. Residual strength measured after cyclic load showed a gradual drop in high performance structure, such as aircraft frames.

The calculated flexural strength, flexural modulus and observed P_{max} for various samples have been tabulated from Table 2 to Table 5.

TABLE 2
Flexural strength and flexural modules for GFRP

S.No	**No. of Cyles**	**P_{max}(N)**	**Flexural Strength (N/mm^2)**	**Slope (N/mm)**	**Flexural Modulus (N/mm^2)**
1	0	748.6	339.490	315.5	20477.16
2	2100	872.8	337.653	423.6	27493.27
3	4200	725.7	314.004	347.11	22528.77
4	6300	961.1	415.860	432	28038.46
5	8400	715.9	309.764	347.23	22536.56
6	1050	706.1	305.524	292.03	18953.87

TABLE 3
Flexural strength and flexural modules for GCG-GFRP

S. No	No. of Cycles	P_{max}(N)	Flexural Strength (N/mm^2)	Slope (N/mm)	Flexural Modulus (N/mm^2)
1	0	1167	504.951	419.14	27203.8
2	2100	1176.8	509.192	415.72	26981.8
3	4200	1000.3	432.822	390	25312.5
4	6300	1019.9	441.302	491.21	31881.4
5	8400	921.9	398.89	526.85	34194.5
6	10500	1137.6	492.23	425.79	27635.4

TABLE 4
Flexural strength and flexural modules for CFRP

S.No	No. of Cycles	P_{max}(N)	Flexural Strength (N/mm^2)	Slope (N/mm)	Flexural Modulus (N/mm^2)
1	0	1961.4	848.68	704.80	45746.18
2	2100	1814.3	785.03	793.35	51491.47
3	4200	2167.3	937.77	991.87	64376.18
4	6300	1873.1	810.47	832.85	54016.23
5	8400	1412.2	611.04	821.9	25759.04
6	10500	1853.5	801.99	798.93	51853.63

TABLE 5
Flexural strength and flexural modules for CGC-GFRP

S.No	No. of Cycles	P_{max}(N)	Flexural Strength (N/mm^2)	Slope (N/mm)	Flexural Modulus (N/mm^2)
1	0	1726	746.82	803.04	52120.38
2	2100	1147.4	496.47	481.33	31240.17
3	4200	1255.3	543.15	729.32	47335.67
4	6300	1019.9	441.3029	491.21	53349.01
5	8400	1471.1	636.533	578.67	37557.91
6	10500	1274.9	551.6394	374.55	24309.74

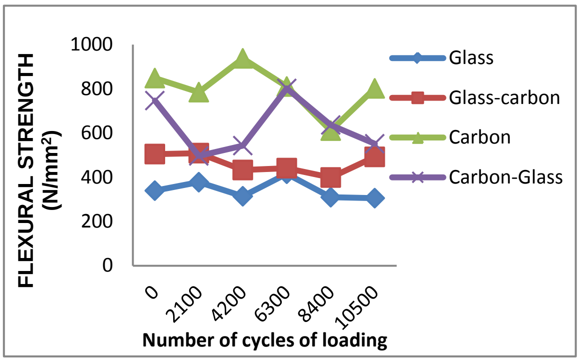

Fig.5. Variation of Flexural Strength of the laminates with respect to number of cycles of cyclic load for 0±90 fiber orientation.

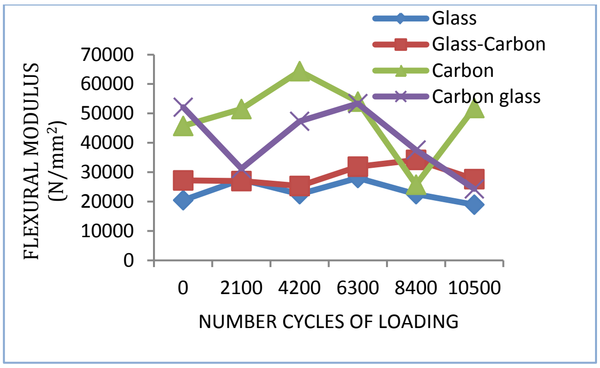

Fig.6. Variation of Flexural Modulus of the laminates with respect to number of cycles of cyclic load for 0±90 fiber orientation

Typically observed flexural strength and flexural modulus for the sample with 0±90 fiber orientation of GFRP, CFRP and glass-carbon(Simply mentioned as glass-carbon in Figure) and carbon-glass(Simply mentioned as carbon-glass in Figure) hybrid composites are illustrated in Fig.5 and Fig.6 respectively. Without any exposure to cyclic loading, obviously plain specimens exhibit some higher flexural strength. Even after the samples have been subjected to low frequency cyclic loading for various cycles the laminates do not lose their strength. The reason for this stability in flexural strength may due to strain toughening of fibers by the introduction of cyclic load. The introduction of more cycles of cyclic load on the specimens reduces the flexural strength gradually and then stiffening taking place in the interface between fibers and matrix with the continuation of loading which is also observed from the Fig.5. Hence, exposure to cyclic loading for certain duration has enhanced the flexural strength of composites under the present investigation. This can be attributed to possible strain toughening of fibers.

It is observed that the overall strength of the hybrid composites under this investigation has been reasonably good. The hybrid composites have lower strength than that of CFRP and it is much better than that of GFRP. Hence, from this study, it is concluded that the inclusion of carbon fiber mat has played a significant role to enhance the flexural strength of the laminates prepared in this study.

V. Summary

The CFRP, GFRP, carbon-glass and glass-carbon hybrid composites have been fabricated by hand lay-up method. The tensile properties have been studied and the breaking load has been measured. The tensile strength of the hybrid composites lie in between the CFRP and GFRP. From the flexural results obtained in this investigation on the 0±90 fiber orientation sample, it is observed that the hybrid samples have intermediate strength after the specimens were subjected to cyclic load. But, the hybrid composites have more flexural strength than that of the GFRP laminates after cyclic load.

Acknowledgement

The authors are thankful to Dr. A. Elayaperumal, Professor of Mechanical Engineering, CEG & Director (Student Affairs), Anna University, Chennai- 600025 for his constant encouragement towards the progress of this work and fruitful suggestions for the betterment of this article.

References

[1] S. Abrate; Composites Engineering Hand book, Marcel Dekker, 1997.
[2] Kailash C. Jajam, Hareesh V. Tippur; Quasi-static and dynamic fracture behavior of particulate polymer composites: A study ofnano-vs. micro-size filler and loading-rate effects,Compos Part B- Eng, Vol.43(8), pp. 3467-3481, 2012.
[3] Feng-Hua Su, Zhao-Zhu Zhang, Wei-Min Liu; Tribological and mechanical properties of Nomex fabric composites filled with polyfluo 150 wax and nano-SiO_2,ComposSciTechnol, Vol. 67 (1), pp. 102-110, 2007.
[4] Feng-Hua Su, Zhao-Zhu Zhang, Kun Wang, Wei Jiang, Xue-Hu Men, Wei-Min Liu; Friction and wear properties of carbon fabric composites filled with nano-Al_2O_3 and nano-Si_3N_4 ,Compos Part A-Appl S, Vol. 37(9), pp. 1351-1357,2006.
[5] Xiaosong Huang, Anil Netravali; Characterization of flax fiber reinforced soy protein resin based greencomposites modified withnano-clay particles,ComposSciTechnol, Vol.67 (10), pp. 2005-2014, 2007.
[6] Yutaka Iwahori, Shin Ishiwata, TomojiSumizawa, Takashi Ishikawa; Mechanical properties improvements in two-phase and three-phase composites using carbonnano-fiber dispersed resin,Compos Part A- Appl S, Vol.36(10), pp.1430-1439, 2005.
[7] M.B.A. Salam, M. V. Hosur, S. Zainuddin and S. Jeelani; Improvement in Mechanical and thermo-mechanical properties of epoxy composites using two different functionalized multi-walled carbon nano tubes, Open J Compos Mater, Vol. 3, pp.1-9, 2013.
[8] S. Rahmanian, K.S. Thean, A. R. Suraya, M. A. Shazed, M. A. MohdSalleh and H. M. Yusoff; Carbon and glass hierarchical fibers: Influence of carbon nanotubes on tensile, flexural and impact properties of short fiber reinforced composites, Mater Design, Vol. 43, pp. 10-16, 2013.
[9] G. Belingardi and M. P. Cavatorta; Bending fatigue stiffness and strength degradation in carbon-glass/epoxy hybrid laminates: Cross-ply vs. angle-ply specimens, Int J Fatigue, Vol. 28, pp. 815-825, 2006.
[10] Chensong Dong and Ian J. Davies; Optimal Design for the flexural behavior of glass and carbon fiber reinforced polymer hybrid composites, Mater Design, Vol. 37, pp. 450-457, 2012.
[11] K.G. Satish, B. Siddeswarappa and K. Mohamed Kaleemulla; Characterization of in-plane mechanical properties of laminated hybrid composites, J Miner Mat Char Eng, Vol.9 (2), pp.105-114, 2010.

[12] P.S. Shivakumar Gouda, S. K. Kudari, S. Prabhuswamy and DayanandaJawali; Fracture toughness of glass-carbon $(0/90)_s$ fiber reinforced polymer composite – An experimental and numerical study, J Miner Mat Char Eng, Vol.10(8), pp.671-682, 2011.
[13] Jin Zhang, KhunlavitChaisombat, Shuai He and Chun H. Wang; Hybrid composite laminates reinforced with glass/carbon woven fabrics for light weight load bearing structures, Mater Design, Vol.36, pp.75-80, 2012.
[14] B. Shivamurthy, K. UdayaBhat and S. Anandhan; Mechanical and sliding wear properties of multi-layered laminates from glass fabric/graphite/epoxy composites, Mater Design, Vol.44, pp.136-143, 2013.
[15] Sam Markkula, H.C. Malecki and Marc Zupan; Uniaxial tension and compression characterization of hybrid CNS-glass fiber-epoxy composites, Compos Struct, Vol.95, pp.337-345, 2013.
[16] K. Pazhanivel, N. Ramadoss, K. Poyyathappan, P. Anandan and G. B. Bhaskar; Flexural analysis on GFRP composites subjected to cyclic gradual load and cyclic impact, Adv Mat Res, Vol. 685, pp. 35-39, 2013.