Modeling and Analysis of GFRP Composite Laminate Using FEA

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Abstract-Advanced Ceramic Composites are increasingly being used in vehicles, missiles and in various space structures. The structural engineer requirement is to well-versed the physical characteristics of structures built up with composite materials. When developing such structures, consideration of the ceramic composite material's performance under dynamic load is essential. In a recent study, an effort is made to present the behavior of a ceramic composite material, namely Glass-Fiber Reinforced Polymers' (GFRP) Composites, under tensile and compressive loading conditions viz experimentation and simulation approaches. Tensile & and compressive tests areperformed under UTM where loads are calculated. The same loads are used in calculating the strength of the composites using Analytical software (Ansys). From the results, it is observed that tensile strength was observed to be 320.24 N/mm^2 and compressive load is observed to be 129.76 N/mm^2. The variation between the simulation and experimentation work is observed to be approximately 1.01%.

Keywords-Glass-Fiber-Reinforced Polymers (GFRP), Tensile strength, Compressive strength, Hand lay-up, fiber angle.

1. INTRODUCTION

A composite material is a combination of two or more materials that exhibits superior qualities than those of the component parts utilized separately. Each substance maintains its unique chemical, physical, and mechanical properties, unlike metallic alloys. A matrix and a reinforcement are the two components. When compared to bulk materials, composite materials' key advantages are their high strength and stiffness paired with low density, which enables weight reduction in the finished item. Strength and rigidity are provided by the reinforcing phase. The reinforcement is often stiffer, stronger, and harder than the matrix. A fibre or a particle is frequently used as reinforcement. Dimensions of particulate composites are roughly identical in all directions. [1]

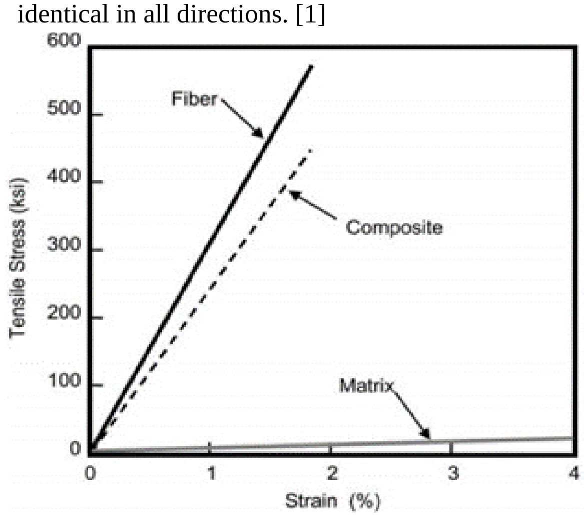

Fig.1: Comparison of tensile properties of fiber, matrix, and composite (Courtesy ASME [1])

It is the traditional and most popular way to create composite structural laminates. Structures are formed using a mold, which is covered with layers of fibers and resin to give it thickness. Air is then removed from the material using a roller. The hand lay-up uses room-temperature curing. High quality is achieved by applying a gel coat. A surface that is exposed to the air is often rough, but it may be cleaned with the right wiping films. In the hand lay-up technique, polyester and epoxies are typically utilized as resin. The line diagram of the hand lay-up procedure is shown in Fig.2. [2]

Table 1: Effect of fiber and matrix on mechanical

properties[1] (Courtesy ASME)

Mechanical Property	**Dominating Composite Constituent**	
	Fiber	**Matrix**
Unidirectional		
[0°]Tension	Yes	No
[0°]Compression	Yes	Yes
Shear	No	Yes
[90°]Tension	No	Yes
Laminate		
Tension	Yes	No
Compression	Yes	Yes
In –Plane Shear	Yes	Yes
Interlaminar Shear	No	Yes

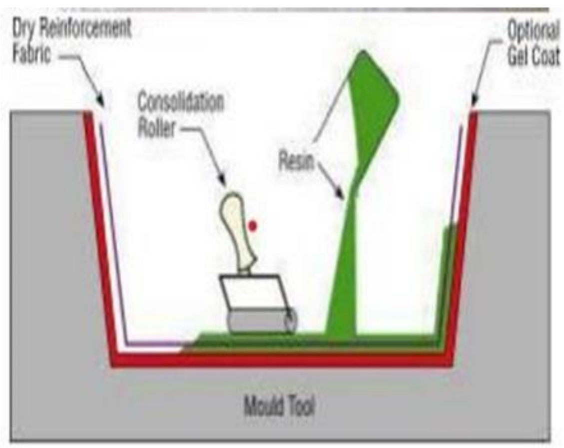

Fig.2: Hand Layup Technique

2. LITERATURE REVIEW

The impact of cutting settings on the surface finish in turning was examined by Davim et al. in 2001. He came to the conclusion that the cutting velocity has the greatest impact on surface roughness, followed by feed, and that the depth of cut has no discernible effect. [3] A theoretical model created by Cenna and Mathew (2002) predicted various laser cutting parameters for GFRP composite materials, including kerf width at the entry and exit, material removal rate, and energy transmission through the cut kerf. [4] Using an alumina grinding wheel, Hu and Zhang et al. (2004) investigated the grinding process of UD CFRP composite materials. It was found that grinding forces are larger when fibres are orientated at 60° and 90°, but that grinding surfaces are poor when fibres are oriented at 120° and 180°. [5]
By using two delamination factors, Grilo, Paulo, Silva, and Davim (2013) evaluated the impact of three different drill geometries and cutting parameters (feed rate and spindle speed). The delaminated area and the largest diameter of the damage zone were measured using a non-destructive method that was based on processed image analyses of the drilled surfaces. [6] Piquet et al. (2000) examined the effects of drilling tool geometry on the drilling quality of thin carbon/epoxy plates and discovered that pre-drilling is required to counteract the chisel edge effect and lubricate the machining process in order for a conventional double fluted twist drill to perform well on these plates. Applying a variable feed rate in proportion to its geometry can further enhance the machining conditions. [7]

The performance of five tungsten carbide drills with 6 mm diameter and various geometries, including a twist drill with a point angle of 120°, a twist drill with a point angle of 85°, a brad drill, a dagger drill, and a special step in drilling CFRP laminate, were examined by Durao et al. (2010). They discovered that the twist drill with 120° point angle always has the highest force but the delamination is the least. [8] Lin and Chen (1996) used tungsten carbide twist drills and multifacet drills to perform high-speed drilling on CFRP laminates and discovered that as spindle speed rose from 9550 rpm to 38650 rpm (from 250 to 850 m/min) (7 mm), both thrust force and torque increased. An acceptable hole entry and exit quality was maintained despite rapid tool wear and a sharp increase in thrust force as cutting speed increased. [9]

Using a CNC milling centre, Mohan, Ramachandra, and Kulkarni (2005) performed a number of experiments on glass fiber-reinforced plastics and discovered that the thrust force and torque are functions of the feed rate and drill size. They then created an empirical relationship that models the relationship between cutting speed and feed rate and the response of the thrust force and torque. [10] In order to quantify the thrust force at the exit of the drilled hole in FRP laminates, Zitoune and Collombet (2007) proposed a numerical finite element analysis model that was function of tool point geometry and the shear force effects in the composite and compared it with analytical models. By carrying out punching experiments at low speeds, they have validated the numerical model on two different types of products made of carbon-epoxy composites. [11]

When drilling CFRP composites using step core drills, Tsao (2008) discovered that the thrust force dramatically lowers when the spindle speed increases from 800 to 1200 rpm. When the diameter ratio is reduced and the feed rate is increased, the thrust force of different step-core drills increases. [12] An L9 orthogonal array was utilized by Vankanti and Ganta (2013) to conduct trials using the Taguchi experimental design to examine the effects of different combinations of process parameters on hole quality. They discovered that the most important component impacting the thrust force is feed rate, which is followed by speed, chisel edge width, and point angle; the most important factor affecting the torque, speed, and circularity of the hole is cutting speed, which is followed by feed, chisel edge width, and point angle. [13] Pro/Engineer, a 3D modeling program, is used in this work to design and model a motorcycle helmet. Using COSMOS software, an impact study is done on the helmet when it collides with a target traveling at different speeds of 50, 60, and 70 kilometers per hour and facing the helmet from the front, right, and back. ABS and PVC are the materials utilized to make the helmet. [14]
The GFRP composite laminate should be stacked in a way that is most advantageous under axial loading conditions; otherwise, a number of more complex failure modes will result from these orientations. The investigations evaluated stress, strain, and deformation using MATLAB and simulation techniques (ANSYS).[15] Experimental methods are used to determine the compressive and tensile strengths of mechanical characteristics. The laminates are made using a hand layup technique.[16]
The goal of this study is to characterise damage that is done to fibre glass laminates by a combination of low velocity, massive impact, and flexural forces. [17]

From the above literature it is observe that very little research has been carried on GFRP composite to study the behavior based on various loading conditions. The main objective of the work is to determine the mechanical characterization of the GFRP composite material under tensile and compressive loading conditions using FEA.

3. SELECTION OF MATERIALS

The final composite engineering and physical material qualities are most strongly influenced by the choice of materials to be utilized, specifically the fiber and resin system, and the manufacturing technique used to create the structure. Most of the qualities are typically controlled by the fibers. There are many different fibers to choose from, but generally, price, weight, and performance determine the final product. As a result, the ASTM D3039 standard as shown in fig.3, glass fiber with the epoxy matrix is chosen for the tensile and compression tests.

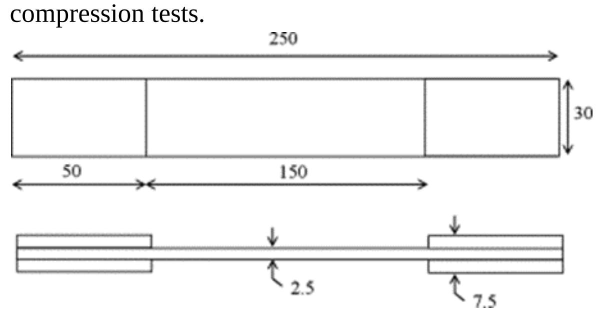

Fig.3: ASTM D 3039 standard dimension used (Image Courtesy [17])

FE ANALYSIS OF GFRP COMPOSITE LAMINATE's
Simulation was carried out on Ansys software. In this process laminate made of GFRP composite having dimensions of length 250mm, width 30mm and thickness of approximately 3mm is analyzed. Load applied to the laminates are taken from the experimentation test that was conducted using UTM machine (UTM) as shown in table 2 to 5. Three specimens were tested for each test and average load is calculated accordingly. The results are shown in fig. 4 to 7.

Table 2: Tensile load for GFRP laminate composites

Specimen	Area of cross section (mm^2)	Tensile load (kN)	Tensile Strength (N/mm^2)
Spe-1	72.83	23.17	318.13
Spe-2	70.31	22.83	324.70
Spe-3	72.38	23.01	317.90
Average		23.00	320.24

Table 3: Compressive load for GFRP laminate composite

Specim e n	Area of cross sectio n (mm^2)	Compressiv e load (kN)	Compressiv e Strength (N/mm^2)
Spe-1	72.83	9.63	132.22
Spe-2	70.31	9.09	129.28
Spe-3	72.38	9.25	127.79
	Average	9.32	129.76

Table 4: FE analysis of Tensile load for GFRP laminate composites

Tensile Load (kN)	Tensile Strength (N/mm^2)
23.17	319.265
22.83	314.58
23.01	317.06
Average Strength	316.968

Table 5: FE analysis of compressive load for GFRP laminate composites

Tensile Load (kN)	compressive Strength (N/mm^2)
9.63	132.694
9.09	125.253
9.25	127.458
Average Strength	128.468

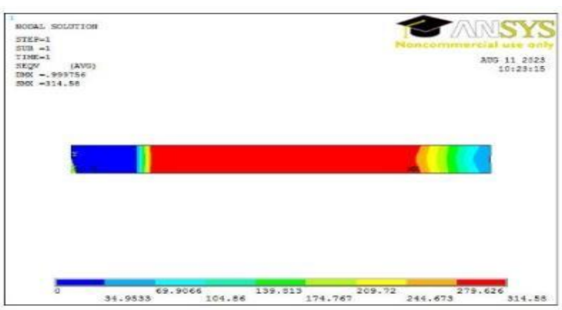

Fig.4: Simulation Results of Tensile Test Specimen at Load 22.83kN

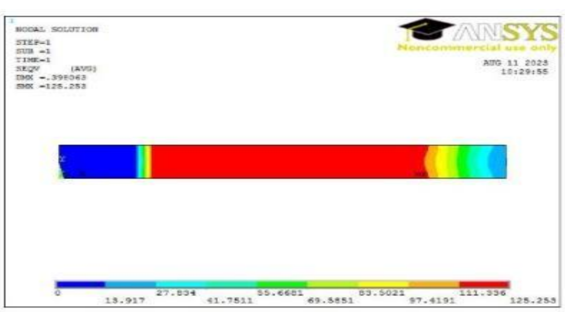

Fig.5: Simulation Results of Compressive Test Specimen at Load 9.09kN

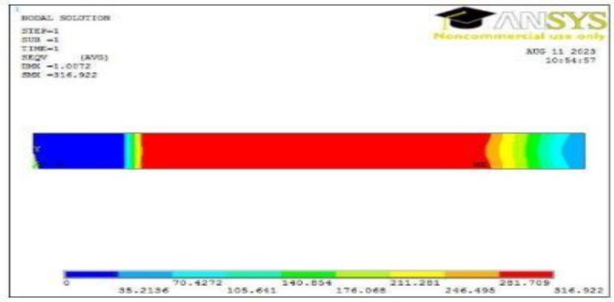

Fig.6: Simulation Results of Tensile Test Specimen for 0° helix angle at Load 23.00kN

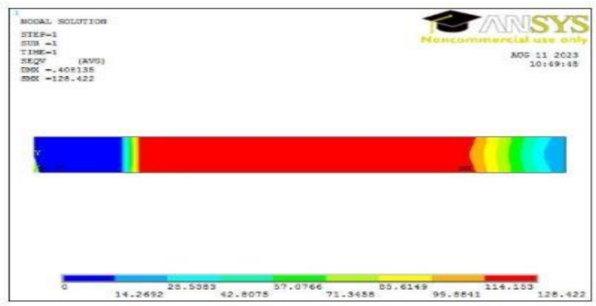

Fig.7: Simulation Results of Compressive Test Specimen for 0° helix angle at Load 9.32kN

4. RESULTS AND DISCUSSION

Composite made of Glass as fiber materials and epoxy as a matrix is fabricated by maintaining the volume fraction of 50% of fiber. The laminates are tested under UTM to perform tensile and compressive loads.
Three specimens were tested for each test, loads that are obtained from the test are noted and average load is calculated at the end for both the tests. From the table 2 is shown that load and area of the cross section are the two parameters that effects the strength. As the load increases or decreases for the specimen based on non- uniform of laminate there is variation in the loads as well as strength. This is because the laminates are prepared using hand layup method. The same is observed to tensile and compressive strength also. Analytical work i.e. using Ansys is carried out to validate the results that are obtained from the experimentation asshown in fig.8&9. It is observed that a variation of about 1.01% is observed in between tensile strength and 1.00% is obtained for compressive strength.

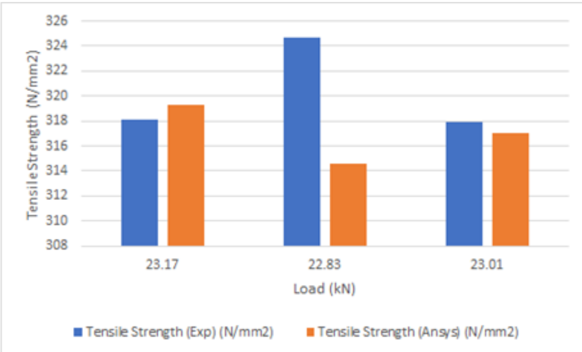

Fig.8: Comparison of Tensile Strength of GFRP Laminate by means of experimental and simulation

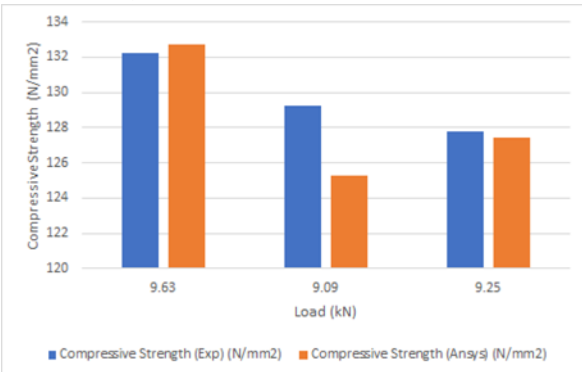

Fig. 9: Comparison of compressive Strength of GFRP Laminate by means of experimental and simulation

5. CONCLUSION

In the present work GFRP composite laminates are prepared by means of Hand Layup procedure. The method for the fabrication of samples is conventional. The important conclusions drawn from the present work are:

1. The tensile strength obtained for the sample Specimen No.2 from the experimental and FE analysis is 324.70 N/mm^2 and 319.265 N/mm^2 for specimen 1 shows a maximum value. The average Tensile strength from experimental work is 320.24 N/mm^2 and from Ansys is 316.968 N/mm^2
2. The compressive strength obtained for the sample Specimen No.1 from the experimental and FE analysis is 132.22 N/mm^2 and132.694 N/mm^2 for specimen 1 shows a maximum value. The average compressive strength from experimental work is 129.76 N/mm^2 and from Ansys is 128.468 N/mm^2
3. The percentage of variation in between the laminates is observed to 1.01% of tensile and 1.00% for compressive strength.
4. [0° - 90°] was the angle selected in the simulation.

REFERENCE

[1]http://www.asminternational.org/documents/10192 / 1849770/05287G_Sample_Chapter.pdf

[2] Sadaq, S. Irfan, et al. "Characterization and mechanical behavior of composite material using FEA." *International Journal of Engineering Research* 2.2 (2013): 125-131.

[3] Davim, J. P (2001). "A note on the determination of optimal cutting conditions for surface finish obtained in turning using design of experiments", J. Mater. Proces. Technol., Vol. 116, pp. 305-308

[4] Cenna, A.A. and Mathew, P. (2002). "Analysis and prediction of laser cutting parameters of fibre reinforced plastics (FRP) composite materials", Inter. J. Mach. Tools Manuf., Vol. 42, pp. 105-113.

[5] Hu, N.S. and Zhang, L.C. (2004) "Some observations in grinding unidirectional carbon fiber-reinforced plastics", J. Mater. Proces. Technol., Vol. 152, pp. 333-338.

[6] Grilo, T. J., Paulo, R. M. F., Silva, C. R. M., & Davim, J. P. (2013). Experimental delamination analyses of CFRPs using different drill geometries. Composites Part B: Engineering. 1344–1350.

[7] Piquet, R., Ferret, B., Lachaud, F. and Swider, P. (2000). "Experimental analysis of drilling in thin carbon/epoxy plate using special drills", Composites: Part A, Vol. 31, pp. 1107-1115.

[8] Durao, L. M. P., Goncalves, D. J. S, Tavares, J. M. R. S., de Albuquerque, V. H. C. and Marques, A. T. (2010). "Drilling process of composite laminates-A tool based analysis", 14th, European Conference on Composite Materials, pp, 1-10.

[9] Lin, S. C. and Chen, I. K. (1996). "Drilling carbon fiber-reinforced composite material at high speed", Wear, Vol. 194, pp. 156-162.

[10] Mohan, N. S., Ramachandra, A., & Kulkarni, S. M. (2005). Machining of Fibrereinforced Thermoplastics: Influence of Feed and Drill Size on Thrust Force and Torque during Drilling. Journal of Reinforced Plastics and Composites, 24(12), 1247–1257.

[11] Zitoune, R., & Collombet, F. (2007). Numerical prediction of the thrust force responsible of delamination during the drilling of the long-fibre composite structures. Composites Part A: Applied Science and Manufacturing, 38(3), 858–866.

[12] Tsao, C. C. (2008). Influence of drill geometry in drilling carbon fibre reinforced plastics. In Key Engineering Materials (Vol. 375–376, pp. 236–240).

[13] Vankanti and Ganta (2013). "Optimization of process parameters in drilling of GFRP composite using Taguchi method", Journal of Materials Research and Technology Volume 3, Issue 1, Pages 35-41

[14] Sadaq, S. Irfan, et al. "Impact Test on Motor Cycle Helmet for Different Impact angles using FEA." *International Journal of Engineering Trends and Technology. [Online]* 12.6: 278-281.

[15] Sadaq, S. Irfan, et al. "Analysis of optimum stacking sequence of GFRP composite laminate under axial loading condition." *Materials Today: Proceedings* 62 (2022): 2940-2945. https://doi.org/10.1016/j.matpr.2022.02.510

[16] Mohd Mohinoddin, S. Irfan Sadaq, Syeda Romana, V. Suvarna Kumar, Experimental characterization of unidirectional carbon – Carbon composite laminate, Materials Today: Proceedings, 2023, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2023.07.079.

[17] S. Irfan Sadaq, V. Suvarana Kumar, G.M. Sayeed Ahmed, Md. Irfan, Experimental Investigation and Impact Analysis of GFRP Composite Laminates, Materials Today: Proceedings, Volume 2, Issues 4–5, 2015, Pages 2808-2816, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2015.07.291.