Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication Online Open Access
Vol: 41 Issue: 11-2022
DOI 10.17605/OSF.IO/VCX68

EFFECT OF ADDING SIO2 NANOPARTICLES ON TENSILE AND BENDING TESTS OF GLASS/CARBON HYBRID COMPOSITE MATERIALS

THAKER S. DAWOOD

Department of Basic Sciences, College of Agricultural Engineering Sciences, University of Duhok, Duhok, Iraq. Email: thaker.saleh@uod.ac

BASIM M. FADHIL

Department of automotive technology, Erbil Technology College, Erbil Polytechnic University, Erbil, Iraq. Email: basim.fadhil@epu.edu.iq

DLAIR O. RAMADAN

Department of Technical Mechanical and Energy Engineering, Erbil Technical Engineering College, Erbil Polytechnic University, Erbil, Iraq. Email: dlair.o.ramadan@epu.edu.iq

Abstract

Fiber glass/carbon hybrid composite laminates have a wide range of uses in machine tools, aerospace, and automotive structures. Many researchers have worked to develop hybrid laminates with the optimal layering arrangement and enhanced static and dynamic stability. In the current work, the influences of fiber orientation and adding SiO_2 on the proven effective layering arrangement of a glass/carbon hybrid composite was examined. Three significant fiber orientations 0^o, 45^o, and 90^o were taken into consideration, along with the addition of SiO_2 nanoparticles as fillers to epoxy to explore the influence of fiber orientation on the effective layering arrangement. By using the infusion process, all of the hybrid laminates were created. The hybrid composite samples were evaluated for mechanical qualities like tensile and flexural strength for more trials in order to understand and analyze the influence of fiber orientation and SiO_2 nano particles. For the tensile and flexural tests, the test pieces have been cut to the standard size set by ASTM. The findings were presented and analyzed. According to the findings, the tensile and flexural strengths increased with increasing the plate thickness and adding the SiO_2 nanoparticles.

Keywords: Hybrid Composite Materials, Tensile Strength, Sio_2 Nanoparticles, Flexural Strength

1 INTRODUCTION

Hybrid composite materials are those that are made of combining two types or more of reinforcement fibers like carbon and glass fibers or combining matrix with particles such as micro and nano silica (SiO_2), to increase failure strains resistant to damage. These composites have the best properties while decreasing cost and improving mechanical properties such as modulus of elasticity and stiffness. In general, when combining two or more different fibers and combining particles with epoxy, it’s feasible that both fibers will combine their benefits while lowering their disadvantages. The most significant scientific difficulties for composite engineers are the creation of new, stronger, and more durable lightweight structural materials that enable cutting-edge technology as well as design principles for complicated shaped constructions like airplanes, automobiles, and massive wind turbine blade structures [1].

Chiang et al. [2] demonstrated that hybridization had no synergistic effect on tensile qualities, which contradicts the conclusions of several prior research papers on the subject. It was found that the hybrid composites exhibit a percentage reduction in tensile strength but an increase in tensile failure stresses. Carbon nanotubes have been recognized as an ideal material for improving quality by introducing them into composite materials. Yutaka Iwahori et al. [3] found that adding carbon nano fiber improved mechanical characteristics in two and three-phase composites. Salam et al. [4] stated that the inclusion of two distinct functionalized multi-walled carbon nanotubes improved the mechanical and thermo-mechanical characteristics of an epoxy composite. Rahmanian et al. [5] investigated the effect of carbon nanotubes on the tension, bending, and impact properties of short fiber reinforced composites. Manders and Bader [6] investigated various glass carbon ratios and stages of dispersion of the two phases. The carbon phase's failure strain increased as the carbon fiber's relative proportion decreased, and the carbon fibers were more finely scattered. The hybrid effect and strain increase of up to 50 percentage for a glass carbon fiber/epoxy composite were explored. Yerramalli and Waas [7] studied a carbon/glass composite material with a 30% volume proportion of total fibers. When the hybrid composites were loaded at dynamic and static loading rates, splitting and kinking failures were observed. Zhang et al [8] examined the mechanical properties of carbon/glass fiber hybrid composites, and the production process used was "wet lay-up," which is not recommended for making high-quality laminates. Murgan et al. [9] found that keeping high-modulus carbon fiber on the outside and low-modulus glass fiber on the inside made glass/carbon hybrid laminates more stable. Murgan et al. [10] developed an excellent layering arrangement for the epoxy-based glass/carbon hybrid composite material. The influence of fiber direction in the optimum effective stacking sequence of hybrid composite laminates on mechanical parameters such as tensile strength and flexural strength was investigated. Poyyathappan et al. [11] used the hand layup process to create bidirectional carbon fiber reinforcement, glass fiber reinforcement, and carbon-glass hybrid laminates. The three-point bend technique was used to investigate flexural characteristics, and the results suggest that hybrid composites have superior flexural properties than GFRP.
Liang et al. [12] It has been shown that incorporating nano-fillers into polymer epoxy resins and fiberglass reinforced plastic (FRP) composites improves the compression behavior of composite systems. Brianqon et al. [13] found that when the continuous glass/epoxy composites are exposed to a transverse load, the micro-grids get deformed, which results in the brittle fracture of the matrix. Benzarti et al. [14] investigated the influence of glass fiber orientations on the properties of epoxy-based composite materials. Due to their low stiffness and fatigue strength in the transverse direction, unidirectional glass fiber reinforced polymer composites are used in industries less than bidirectional glass fiber reinforced polymer composites. Brocks et al. [15] investigated the influence of carbon fiber surface features and interfacial adhesion difference on the flexural properties of structural composites. In a study conducted with the help of dynamic analysis technique. Bajuri et al. [16] have developed a hybrid

kenaf/silica nanoparticle in an epoxy composite, in which silica nanoparticles were used as a filler ingredient, which was then tested. To enhance the flexural and compressive characteristics of the material, silica nanoparticles with a volume of 2 percent must be used. Wang et al. [17] have investigated the influence of fiber orientation on the Young's modulus of unidirectional E-glass reinforced composites in epoxy matrix in their research. Their findings revealed that the elastic modulus of the composites is substantially dependent on the fiber direction angles ranging from 0o to 90o. Chensong Dong and colleagues [18] investigated the compressive and flexural characteristics of epoxy composites reinforced with glass and carbon fiber. Failure occurs more often in compressive than in flexural tests, and an increasing number of fibers resulted in a decrease in flexural modulus. Linqi Zhuang et al. [19] studied the formation of a critical fracture plane that simulates the local failure region in a unidirectional composite. A matrix crack starts at the broken end of a fiber and grows along the fiber axis. A short fiber/matrix de-bond crack causes a crack to kink and grow toward the other fibers. The present study aims to develop a new hybrid resin system that could be based on silica nanoparticles for the fabrication of unidirectional hybrid glass-carbon fiber composites. The silica nanoparticles could be used as fillers since they possess high hardness and also a high crystalline structure, and their effect on the composite material can be seen by examining the tensile and bending strength.

2 METHODOLOGIES

2.1 Material Selection

Hybrid composite materials are made up of two or more components such as low modulus and high elongation glass fibers that are combined with carbon fibers to make the compound more damage resistant and, as a result, have great effect characteristics while reducing manufacturing costs. These characteristics are shown in Table 1.

Table 1: Materials specifications using to fabricate laminates

Glass fiber reinforcement	unidirectional (Glass Fabric Unidirectional-300 gr/sqm)
Carbon fiber reinforcement	unidirectional (Carbon Fabric Unidirectional-300 gr/sqm Thermofixed)
Matrix (liquid)	Epoxy resin MGS (LR 285)
Hardener (liquid)	MGS (LH 287)
(Silicon Dioxide) Nanoparticles	15-35nm, Purity 99.5+%, amorphous
Fiber’s volume fractions	0.4

2.2 Fabrication of Composite

Samples of Composite Materials Were Prepared from glass fibers, carbon fibers, and resins with a volume fraction of 50%. As well as samples of composite materials from glass fibers, carbon fibers, and resin with 2% SiO_2 nano-silica particles were added and with a volume fraction of 50% as a first group, to calculate the mechanical properties of each of the carbon plate and glass plate with resin and with the resin added with 2%

SiO_2 nano-silica particles as shown in ***Error! Reference source not found.***. The other sets of hybrid samples were prepared as a second group of glass fibers, carbon fibers, and resins with 2% SiO_2 nano-silica particles with different thickness (8, 10, and 12) layers and a volume fraction of 40%, as shown in Table 2.

Table 2 : Stacking sequence of hybrid laminates

Samples	Composite type	Stacking Sequences	Numbers Layers	Area mm2	Thickness mm	Density g/cm3	Weight g
S1	[G/C/G/C] s	[0/45/90/0] s	8	250000	2.4	1.621	1037.6
S2	[G/C/G/C/G] s	[0/45/90/0/45] s	10	250000	2.65	1.662	1297
S3	[G/C/G/C/G/C]s	[0/45/90/0/45/90]s	12	250000	2.84	1.672	1556.4
S1N	[G/C/G/C] s	[0/45/90/0] s	8	250000	2.42	1.657	1037.6
S2N	[G/C/G/C/G] s	[0/45/90/0/45] s	10	250000	2.66	1.690	1297
S3N	[G/C/G/C/G/C]s	[0/45/90/0/45/90]s	12	250000	2.87	1.689	1556.4
S	Plates without SiO_2 Nano particles						
SN	Plates with SiO_2 Nano particles						
G	Glass fibers						
C	Carbon fibers						

The methods of manufacturing composite materials are numerous, and each method has its advantages and disadvantages, each of which has an appropriate field in which it is applied. The vacuum bag technique and cured at 80o C for about 15 hours were used in preparing the samples regardless of the laminated material. It applies a strong clamping pressure and is uniformly distributed over the entire surface. It is possible to obtain samples of different shapes, sizes, and dimensions, and these samples are good as they are free of bubbles by about 99%.

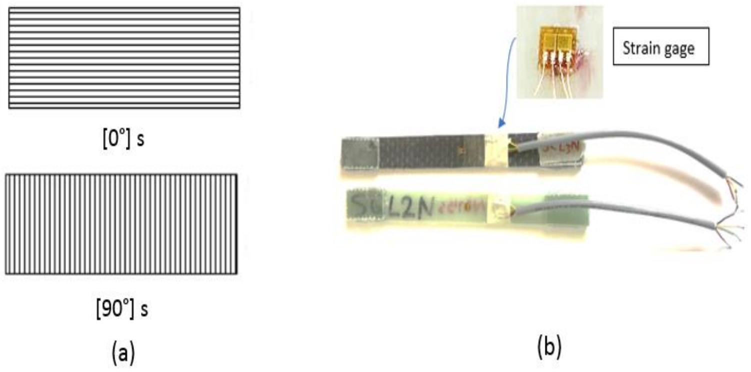


Fig. 1. a- staking configuration b- Strain gage for computing E1 and E2

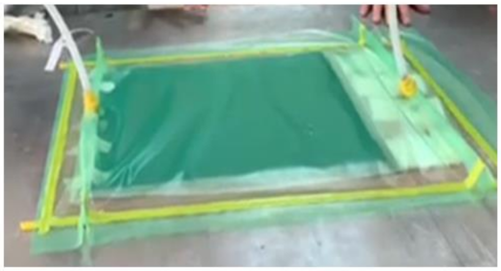


Fig. 2 : Vacuum bag and curing method

Fig. 3: Ultrasonic processes for small and medium volume application.

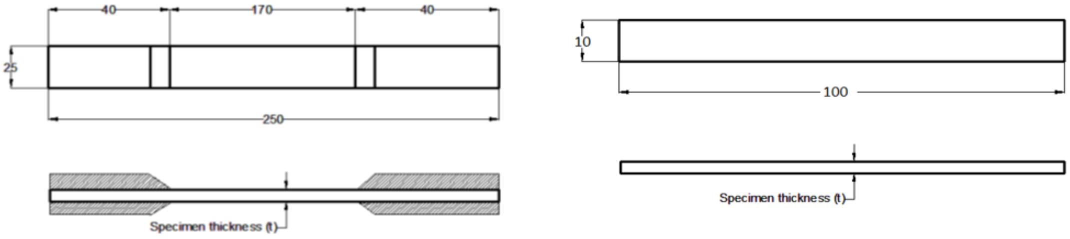
To manufacture the laminate evenly throughout the glass and carbon plies with the required stacking sequence manually and putting the peel ply on top, it is a special cloth to prevent the plate from sticking with infusion mesh. When correctly sealing the vacuum bag, switch on the vacuum device after closing the resin's unique intake and outlet tubes until the pressure gauge reaches 760 mm-Hg, then shut the system and wait 30 minutes to ensure that the vacuum bag is leak-free. When the temperature of the base reaches 80o Centigrade, the resin is allowed to enter the vacuum bag, after ensuring the resin permeation between the fibers, the tubes are closed tightly and left for 15 hours as a curing process as shown in **Error! Reference source not found.**. For laminates that have SiO2 nanoparticles, they can be mixed with resin by using a SONICS device (ultrasonic nanoparticle dispersion) as shown in **Error! Reference source not found.**. This device can mix nanoparticles with a uniform distribution.

2.3 Preparation of Specimens

The DIAMANT RUBI cutter, shown in Figure 4, was used to cut specimens of appropriate proportions from the composite plates for various ASTM mechanical tests. Tensile test specimens with dimensions of 250 mm in length, 25 mm in breadth, and (t) mm in thickness as shown in **Error! Reference source not found.**-a were created using ASTM D3039 [20]. The bending test specimens were manufactured according to

ASTM D790 [21], with dimensions of 100 mm in length, 10mm in width, and (t) mm in thickness as shown in **Error! Reference source not found.**-b.

Fig. 1: Diamant Rubi Cutter.



(a) (b)

Fig. 5: Dimensions test specimens for (a) Tensile Test ASTM D3039, (b) Bending Test ASTM D970.

2.4 Tensile test

Tensile test specimens were performed in accordance with ASTM D3039 and done on the Shimadzu device, a load cell rated at 100 KN and a cross - head velocity of 2 mm/min were used as shown in

Fig. ***2***. Five identical test specimens were employed for each fiber orientation to determine the composites tensile (elastic) modulus, tensile load, tensile strength as shown in

Fig. 3.

Fig. 2: Universal Testing Machine with a force capacity of 100 KN (SHIMADZU).

Fig. 3: Tensile test specimens.

2.5 Three points bending test

Flexural testing was performed in accordance with ASTM D790. The test was done on the Shimadzu machine with a 100 kN load cell loaded at a rate of 1 mm/min as shown in Fig. **8**. The specimen is supported freely by a beam, and the load is applied at the specimen's center. The tests were conducted at room temperature. Five samples were analyzed for statistical reasons. Figure 9 illustrates the specimens of the flexural test [13].

$$E_F = mL^3/4bt^3 \tag{1}$$

Where:
E_F = Flexural modulus (Gpa),
m = slop of the tangent to the initial straight-line portion of the load-deflection curve (N/mm^2),

L = Support span (mm),
b = Width of beam tests (mm),
t = Thickness of beam tests (mm),

Fig. 4: Three points bending test.

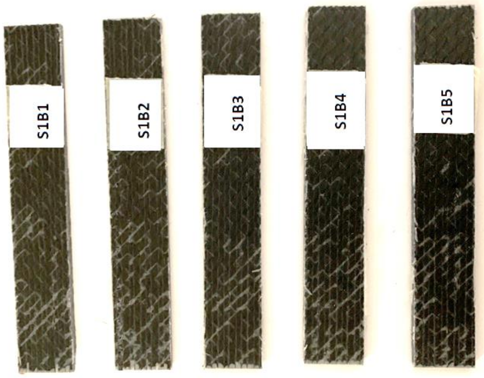


Fig. 5. Three points bending specimens.

3. RESULTS AND DISCUSSION

Table 3 shows the effect of adding SiO2 nano-silica on the mechanical properties of glass and carbon-made laminates. As can be seen from the table, the glass-made laminates reported significantly higher longitudinal and transverse modulus of elasticity, shear modulus, Poisson's ratio, and density than the carbon-made laminates. These results are likely to be related to structural condensation, leading to improved mechanical properties as shown in Figure 10.

Table 3 : Mechanical properties of glass and carbon fibers.

Sample	**Material**	**E 1 Gpa**	**E 2 Gpa**	**G 12 Gpa**	**v12**	**Density g/cm3**
G[08]	Pure Glass/Epoxy	31.802	12.804	4.271	0.22	1.658
G[08]	Pure Glass/Epoxy with nanoparticles	33.361	13.408	4.48	0.27	1.842
C[08]	Pure Carbon/Epoxy	99.438	6.273	4.031	0.25	1.484
C[08]	Pure Carbon/ Epoxy with nanoparticles	101.604	6.41	4.12	0.30	1.506

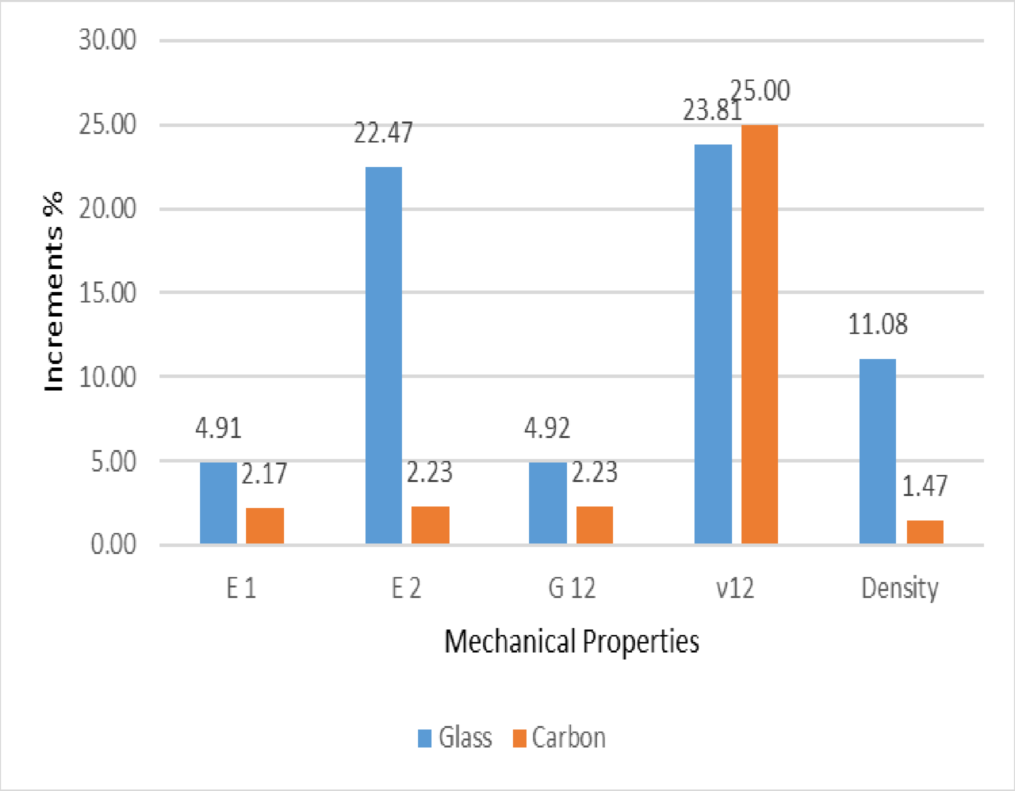
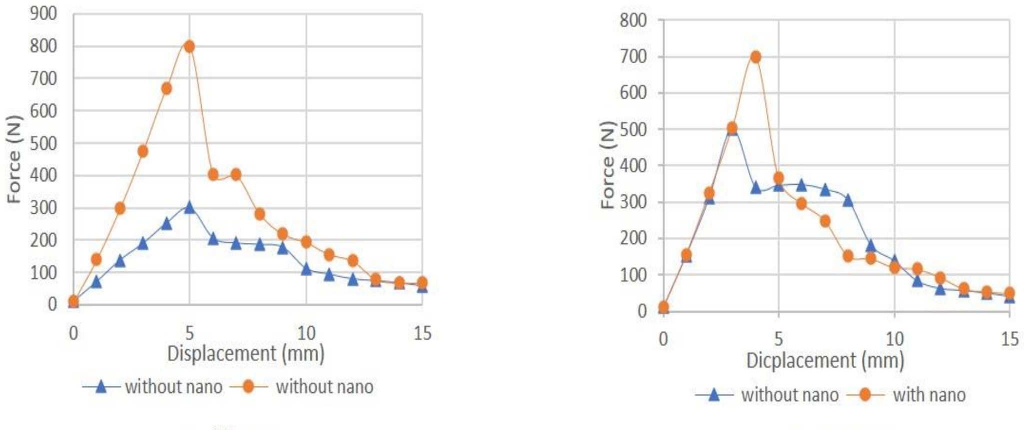


Fig 10: Increment percentage of mechanical properties

It was noted that tensile strength at the breakage increased with the increase in the number of layers, and this is due to the contribution of both glass fibers and carbon fibers in resisting the forces exerted on hybrid composite materials in proportion to their nature, direction, and volume fraction[22]. Epoxy plays an important role in stress bearing. And as it is clear from Figure 11, when adding 2% of SiO2 nano particles to

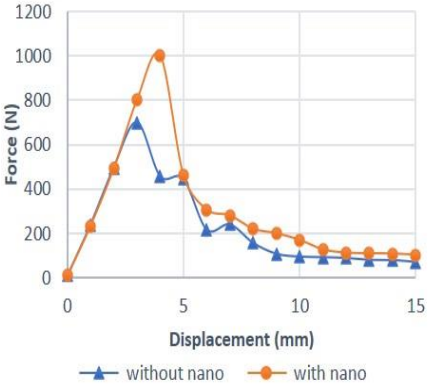
Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication Online Open Access
Vol: 41 Issue: 11-2022
DOI 10.17605/OSF.IO/VCX68

epoxy, it increases the tensile strength by 8.3%, 5.5%, and 18.7% for each of 8-layers, 10-layers, and 12-layers, respectively, and as a result of that, the addition of nanoparticles to composite materials gives durability to the hybrid compound due to its random and regular distribution and ease of penetration into the epoxy[16]. **Error! Reference source not found.** shows that samples with nano-silica particles in them have a better tensile strength than similar samples that don't have nano-silica particles in them.



a. 8-layers

b. 10-layers



c. 12-layers

Fig.11: Effect of adding SiO2 nanoparticles on tensile-displacement test

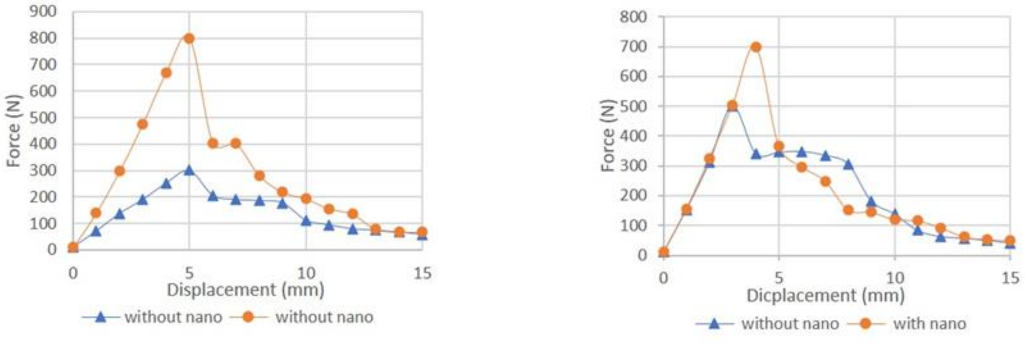
Table 4: Mechanical properties of hybrid laminates at tensile test

Samples	Modulus of elasticity E1(Gpa)	Maximum tensile load (N)	Maximum tensile stress (N/mm2)
S1	10.93	22442.68	374.05
S1N	11.75	24304.92	405.08
S2	11.07	26497.91	399.97
S2N	11.67	27953.25	421.94
S3	12.11	25090.06	352.14
S3N	14.65	29779.35	417.96

The contribution of glass fibers, carbon and nano particles of silica to the strength of the forces acting on the hybrid composite materials according to their type, direction and ratio can be observed by noting that the resistance to bending at break increases with the number of layers. It is essential to the epoxy's ability to withstand tension. The bending resistance increased by 148%, 38% and 63% in all three samples containing nano-silica for 8, 10 and 12 layers, respectively. Figure 12 depicts three models without SiO2 nanoparticles and three models with 2% SiO2 nanoparticles in the epoxy. The curves show the same linear behavior before divergence. The point at which the line stops straight is the point at which the fracture of the material begins to cause failure. Table 5 shows that the slope of the tangent line, the maximum flexural load, and the flexural modulus all go up in samples with SiO2 nano particles[23]. From the above, we can say that when adding silica nanoparticles in a certain proportion to the hybrid composite materials, the bending strength is significantly greater than the tensile strength.

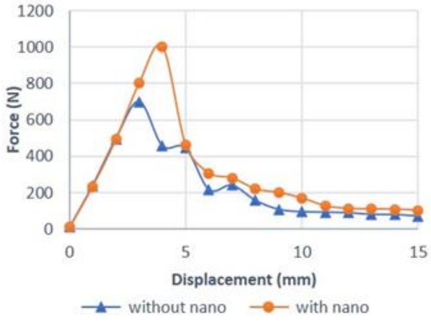
Table 5 : mechanical properties of hybrid laminates at bending test

Samples	Slope of tangent line (Mpa)	Maximum flexural load (N)	Flexural Modulus EF (N/mm2)
S1	60.422	298.9981	23602.34
S1N	170.44	739.8553	66578.12
S2	130.64	480.9062	51031.25
S2N	170.75	665.5269	66699.21
S3	180.7	605.793	70585.93
S3N	300.51	986.8887	117386.72



a. 8-layers

b. 10-layers



c. 12-layers

Fig 12: Effect of adding SiO2 nanoparticles on Bending-displacement test

4. CONCLUSIONS

The effect of fiber orientation on effective layer arrangement and nano-silica addition of glass/carbon hybrid composite sheets in terms of mechanical properties was studied. The results of this work clearly showed the effect of the hybrid, whose range depends on the thickness of the samples, the direction of the reinforced fibers, and the hybrid nano-silica resin. The results of this work clearly confirmed the effect of the hybrid. The test of tensile and bending strength for semi-static load was carried out by preparing test samples according to ASTM standard size, and the results were as follows:

1. The presence of SiO_2 nanoparticles in the hybrid composite sheets increases the tensile and flexural strengths.
2. Enhancing the plate thickness has an obvious influence on increasing the bearing of tensile and flexural strength.
3. In the S3N sample, the maximum tensile load increased by about 19%, while for the same sample, the maximum bending load increased by about 63%.
4. When silica nanoparticles are added to the hybrid composite materials, they have greater resistance to bending than tensile strength.

REFERENCES

1. G. M. N and A. N. H. Rao, “A Review on Recent Applications and Future Prospectus of Hybrid Composites,” International Journal of Soft Computing and Engineering (IJSCE). Vol. 1, no. 6. pp. 352–355, Jan. 2012.
2. M. Y. M. Chiang, X. Wang, C. R. Schultheisz, and J. He, “Prediction and Three-Dimensional Monte-Carlo Simulation for Tensile Properties of Unidirectional Hybrid Composites,” Composites Science and Technology, vol. 65, no. 11. pp. 1719–1727, April 2005, doi: 10.1016/j.compscitech.2005.02.012.
3. Y. Iwahori, S. Ishiwata, T. Sumizawa, and T. Ishikawa, “Mechanical Properties Improvements in Two-Phase and Three-Phase Composites Using Carbon Nano-Fiber Dispersed Resin,” Composites Part A: Applied Science and Manufacturing, vol. 36, no. 10. pp. 1430–1439, Oct. 2005, doi: org/10.1016/j.compositesa.2004.11.017.
4. M.B.A. Salam , M.V. Hosur, N. Jahan , M.M. Rahman , and S. Jeelani. “Improvement in Mechanical and Thermo-Mechanical Properties of Carbon Fibre/Epoxy Composites Using Carboxyl Functionalized Multi-Walled Carbon Nanotubes,” Open Journal of Composite Materials, vol. 3, no. 2A. pp. 495–508,Jan. 2013. doi:10.4236/ojcm.2013.32A001
5. S. Rahmanian, K. S. Thean, A. R. Suraya, M. A. Shazed, M. A. Mohd Salleh, and H. M. Yusoff, “Carbon and Glass Hierarchical Fibers: Influence of Carbon Nanotubes on Tensile, Flexural and Impact Properties of Short Fiber Reinforced Composites,” Materials and Design, vol. 43, no. 3. pp. 10–16,Jan. 2013, doi: org/10.1016/j.matdes.2012.06.025.
6. P. W. Manders and M. G. Bader, “The Strength of Hybrid Glass/Carbon Fibre Composites,” J. Mater. Sci., vol. 16, no. 8, pp. 2246–2256, Aug. 1981.
7. C. S.Yerramalli and M.Waas, “Compressive behavior of hybrid composites,” in Structural Dynamics and Materials Conference, vol. 2, pp. 979–987, Feb.2003, https://hdl.handle.net/2027.42/76187
8. J.Zhang, K. Chaisombat, S. He and C. H.Wang. “Hybrid Composite Laminates Reinforced With Glass-Carbon Woven Fabrics For Lightweight Load Bearing Structures,” J. Mater. Des., vol. 36, pp. 75–80,April 2012, doi: org/10.1016/j.matdes.2011.11.006.
9. R. Murugan, R. Ramesh, and K. Padmanabhan, “Investigation of the mechanical behavior and vibration characteristics of thin walled glass/carbon hybrid composite beams under a fixed-free boundary condition,” Mech. Adv. Mater. Struct., vol. 23, no. 8, pp. 909–916,Mar. 2016, doi: org/10.1080/15376494.2015.1056394.
10. R. Murugan, R. L. Narasimhan and A. Harish. “Effect of Fiber Orientation on Effective Stacking Sequence of Glass/Carbon Hybrid Composite Laminates for Structural Applications,” in International Conference for Phoenixes on Emerging Current Trends in Engineering and Management (PECTEAM 2018) Effec. Vol. 142, pp. 204–209, April 2018.
11. K. Poyyathappan, G. B. Bhaskar, K. Pazhanivel, and N. Venkatesan, “Tensile and Flexural Studies on Glass - Carbon Hybrid Composites Subjected to Low Frequency Cyclic Loading,” International Journal of Engineering and Technology, vol. 6, no. 1. pp. 83–90, Mar.2014.
12. S. L. Valença, S. Griza, V. G. de Oliveira, E. M. Sussuchi and F.G.C.D.Cunha. “Evaluation of The Mechanical Behavior of Epoxy Composite Reinforced With Kevlar Plain Fabric and Glass/Kevlar Hybrid Fabric,” Compos. Part B Eng., vol. 70, pp. 1–8, Mar.2014, doi: org/10.1016/j.compositesb.2014.09.040.
13. C. Brianqon, P.Sigety and C. G'Sell. “In Situ Study of Matrix Strain in Carbon/Resin Composite Materials,” Compos. Sci. Technol., vol. 56, pp. 835–840, 1996, doi: org/10.1016/0266-3538(96)00029-2.

14. K. Benzarti, L. Cangemi and F.Dal Maso “Transverse Properties Of Unidirectional Glass/Epoxy Composites:Influence Of Fibre Surface Treatments,” Compos. Part A Appl. Sci. Manuf., vol. 23, no. 2, pp. 197–206,Feb. 2001, doi: org/10.1016/S1359-835X(00)00136-6.
15. T. Brocks, M. Odila, H. Cioffi and H. Jacobus “Effect Of Fiber Surface On Flexural Strength In Carbon Fabric Reinforced Epoxy Composites,” Journal Applied Surface Science. Vol. 274, pp. 210–216,June 2013, doi: org/10.1016/j.apsusc.2013.03.018.
16. F. Bajuri, N. Mazlan, M. R. Ishak, and J. Imatomi, “Flexural and Compressive Properties of Hybrid Kenaf/Silica Nanoparticles in Epoxy Composite,” Procedia Chemistry Journal, vol. 19. pp. 955–960, 2016, doi: org/10.1016/j.proche.2016.03.141.
17. H. W. Wang, H. W. Zhou, L. L. Gui, H. W. Ji, and X. C. Zhang, “Analysis of Effect of Fiber Orientation on Young’s Modulus For Unidirectional Fiber Reinforced Composites,” Composites Part B: Engineering, vol. 56. pp. 733–739, Jan.2014, doi: org/10.1016/j.compositesb.2013.09.020.
18. C. Dong and I. J. Davies, “Flexural Strength Of Bidirectional Hybrid Epoxy Composites Reinforced By E Glass And T700S Carbon Fibres,” Composites Part B: Engineering, vol. 72. pp. 65–71, April, 2015, doi: org/10.1016/j.compositesb.2014.11.031.
19. L. Zhuang, R. Talreja, and J. Varna, “Tensile Failure of Unidirectional Composites From A Local Fracture Plane,” Journal of Composites Science and Technology, vol. 133. pp. 119–127,Sep. 2016, doi: org/10.1016/j.compscitech.2016.07.023.
20. ASTM International, “Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials,” Designation: D3039/D3039M − 17 Standard. pp. 1–13, 2020.
21. ASTM International, “Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials,” Designation:D790-17. pp. 1–12, 2020.
22. M. A. Caminero, G. P. Rodríguez, J. M. Chacón, and I. García-Moreno, “Tensile and flexural damage response of symmetric angle-ply carbon fiber-reinforced epoxy laminates: Non-linear response and effects of thickness and ply-stacking sequence,” Polymer Composites, Vol. 40, no. 9. pp. 3678–3690, Jan. 2019, doi: 10.1002/pc.25230.
23. A. A. Ekram , N. J. Jubier and K. J. Majeed. “Fatigue behavior of Epoxy/ SiO2 NanocompositesReinforced with E- glass Fiber,” Int. J. Appl. or Innov. Eng. Manag., vol. 2, no. 9, pp. 62–69,Sep. 2013.