Effect of Fiber Layer alteration on Mechanical Properties of Polymer Composites synthesis through VARTM Process

Vikash Gautam, Monika Khurana, Deepak Kumar, Manoj Kumar Sain
Department of of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur-302017 (INDIA)
Email: **vikash.gautam@skit.ac.in, monika.khurana@skit.ac.in, deepak.kumar@skit.ac.in, manoj.sain@skit.ac.in**
Received 19.11.2025 **received in revised form** 05.04.2025, **accepted** 07.04.2025
DOI: 10.47904/IJSKIT.15.1.2025.82-85

Abstract- This study investigates wind energy as a crucial power source within the renewable energy sector, with a particular focus on the use of synthetic fiberglass and carbon fiber-reinforced polymer composites in the production of wind turbine blades. By altering the arrangement of fiber layers, there is potential to enhance the mechanical properties of these polymer composites. The article examines how different fiber layer configurations affect the mechanical characteristics of the composites. Two types of synthetic fibers, along with epoxy as the base material, are utilized for these layer modifications. The composite structures are synthesized through the VARTM process, incorporating various fiber layer configurations, including C/C/C/C, G/G/G/G, C/G/C/G, C/G/G/C, and C/G/G/C. Once fabricated, both physical properties (such as theoretical and experimental density, and void content) and mechanical properties (including tensile, flexural, hardness, and impact tests) are comprehensively characterized. The results for void content show that panels with the same fiber type have the lowest void content, while panels with different fiber types exhibit higher void content. Among all the configurations tested, the C/C/C/C layer panel exhibits the best mechanical performance. Furthermore, alternating fiber layers in the C/G/C/G, C/G/G/C, and C/G/G/C panels enhances the mechanical properties when compared to the G/G/G/G layer panel. These findings clearly highlight that modifying fiber layer arrangements significantly affects the composite properties.

Keywords– Fiber, VARTM, Polymer Composites, Mechanical Characterization.

1. INTRODUCTION

Fiber Reinforced Polymer (FRP) composites are transforming the wind energy industry by enabling the creation of more efficient, durable, and innovative turbine components. Their integration into wind turbine blades, towers, and other parts highlights their critical role in advancing renewable energy technology and supporting sustainable energy solutions. As manufacturing processes and materials technology progress, the impact of FRP composites in wind turbines is projected to grow, boosting the effectiveness and sustainability of wind energy as a clean power source. Recent trends emphasize the development of larger blades to reduce wind energy costs, especially for offshore applications. Glass fiber (GF) is widely used in blade reinforcement due to its low cost and adequate mechanical properties, though its weight and rigidity pose limitations. Carbon fiber (CF), with its superior strength and lower density, is well-suited for larger blades; however, its high cost restricts its widespread use. Hybrid composites of glass and carbon fibers offer a promising alternative, balancing cost with enhanced mechanical performance [1-3].

Recent studies have extensively explored the mechanical properties of glass/carbon hybrid composites, with a strong focus on interply hybrid designs, especially those that leverage fiber strengths [4]. For instance, Czél [5] combined carbon fiber (CF) with hybridized glass fiber to create pseudo-ductile composites aimed at safer structural applications. Paulius and Subadra [6] reported increased ductility in the flexural strength of these hybrid composites. Similarly, Lyu and colleagues [7] studied the impact of low-velocity loading on carbon composites with glass hybrid effects, finding improvements in impact resistance.

Fiber hybridization serves as an effective approach to combine the beneficial properties of each fiber type while minimizing their individual weaknesses [8]. This method allows for improved mechanical performance at a reduced overall cost. Additionally, the stacking sequence is essential to achieve desired hybrid characteristics in composite materials [7-9].

Different stacking configurations can be optimized based on the specific loading types expected for wind turbine structures, offering a wide range of design possibilities [10-17].

Wind turbines, however, face dynamic loads such as impact from hail, rain, bird strikes, or maintenance tools [18]. They are also subject to fatigue loading, both short-term and long-term, which influences damage patterns and progression [19-21]. These conditions may lead to visible or hidden damage within the composite materials, potentially resulting in critical failures. Since the blades are the longest structural component in a wind turbine, their orientation and durability are fundamental design considerations [22].

The main objectives of research work to synthesis a set of polymer composites with fiber layer alteration using VARTM process after that explore the effect of fiber layer alteration on mechanical properties of polymer composites synthesis through VARTM process.

2. MATERIALS & METHODS

In this research, bi-directional woven carbon fiber with a 7 micron fiber diameter, 0.20 mm thickness, and 200 grams per square meter (GSM), as well as bi-directional woven glass fiber with a 9 micron fiber diameter, 0.15 mm thickness, and 200 grams per square meter (GSM), were used as reinforcement, with epoxy resin serving as the matrix material. The fiber-reinforced composites were synthesized using the Vacuum Assisted Resin Transfer Molding (VARTM) technique. The VARTM process included the following steps:

1. Mold Preparation: A ceramic mold measuring 20 cm x 30 cm was designed and fabricated to accommodate the composite specimen. The mold had a smooth surface finish, ensuring optimal contact with the composite material during the fabrication process.

2. Vacuum Bag: A flexible vacuum bag was used in the process and connected to a vacuum pump. Its primary function was to exert pressure on the resin and eliminate any air pockets from the mold, ensuring a uniform resin distribution.

3. Vacuum Chamber: The vacuum chamber, a stainless-steel container, was used to protect the vacuum pump by preventing resin from flowing back into the pump during the process.

4. Resin Infusion System: This system included a reservoir, pump, and a network of tubes and valves. The resin and hardener were mixed in the reservoir, then infused into the mold through the tubes and valves, ensuring an even distribution of resin throughout the composite.

5. Safety Equipment: To protect the operator, safety equipment such as gloves, safety glasses, and a fire extinguisher was used. These items safeguarded against potential hazards associated with the resin infusion process.

Figure 1: Matrix and Reinforcement Material

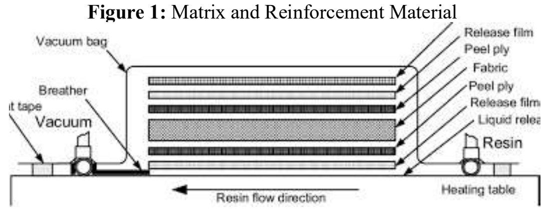

Figure 2: Schematic diagram of Vacuum resin transfer molding technique

2.1 Physical and mechanical characterization:

To identify any fabrication flaws within the composites, density and void content tests were conducted. Theoretical density was calculated using the Agarwal & Broughtman mathematical expression, while experimental density was determined via the Archimedes principle. The void content, indicating deviations between experimental and theoretical density, helped assess the quality of the composite.

2.2 Mechanical testing was conducted as follows:

1. Tensile Test: Performed according to ASTM D3039-3062 standards using a computerized Universal Testing Machine (UTM). Specimens measured 150 × 25 × 2.5 mm, with a crosshead speed of 1 mm/min.

2. Flexural Test: Conducted per ASTM D3039 standards using the UTM. Specimen dimensions were 75 × 15 × 2.5 mm, with a crosshead speed of 1 mm/min and a span length of 45 mm.

3. Impact Test: Impact energy was determined as per ASTM D256 standards. Specimens measured 55 × 25 × 2.5 mm.

4. Vickers Hardness Test: Performed on specimens with a minor load of 100 gm and a major load of 500 gm, using a dwell time of 60 seconds.

3. RESULT & DISCUSSION

Effect of fiber layer alteration on density and void content

To assess the quality of the fabricated samples, density and void content experiments were conducted, with results represented in graphical form (Figure 3). The graph clearly indicates that panels fabricated with uniform fiber layers exhibit minimal void content, while panels with alternating fiber layers show increased void content. This increase in void content is likely due to differences in fiber diameters, which may impact the resin flow and result in variations in material compactness.

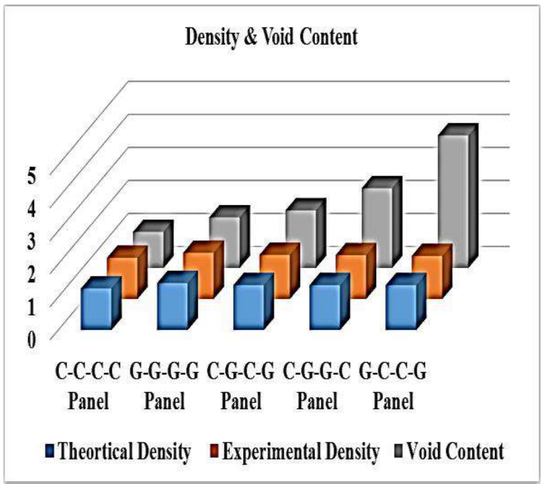

Figure 3: Effect of fiber layer alteration on density and void content

Effect of fiber layer alteration on mechanical performance

The experimental results for various mechanical properties are presented graphically in Figure 4. The figure shows that fiber layer alteration significantly affects the mechanical properties of the fabricated panels. The C-C-C-C panel demonstrates superior mechanical properties, while the G-G-G-G panel shows the lowest performance. Among the fiber-altered panels, those with an outer layer of carbon fiber exhibit better properties, likely due to the superior mechanical properties of carbon fiber compared to glass fiber.

Key mechanical property results include:

1. Tensile Strength: Four-layer carbon fiber composites exhibit a tensile strength of 480 MPa, compared to 310 MPa for four-layer glass fiber composites. In fiber-altered composites, panels with an outer layer of carbon fiber achieve 425 MPa, while those with an outer layer of glass fiber reach 350 MPa.

2. Flexural Strength: Four-layer carbon fiber composites achieve a flexural strength of 520 MPa, whereas four-layer glass fiber composites reach 350 MPa. For fiber-altered composites, panels with an outer layer of carbon fiber exhibit 475 MPa, while those with an outer layer of glass fiber attain 380 MPa.

3. Hardness (Vickers): Four-layer carbon fiber composites reach a hardness of 60 HV, while four-layer glass fiber composites attain 35 HV. In fiber-altered composites, panels with an outer layer of carbon fiber achieve 52 HV, while those with an outer layer of glass fiber reach 40 HV.

4. Impact Energy: Four-layer carbon fiber composites show an impact energy of 115 J, compared to 65 J for four-layer glass fiber composites. Fiber-altered composites with an outer layer of carbon fiber achieve 95 J, while those with an outer layer of glass fiber reach 78 J.

These results align with findings from Demir et al. [22] on carbon/glass fiber reinforced epoxy composites, Chan et al. [13] on carbon/basalt/glass hybrid FRP composite laminates, and Badie et al. [12] on carbon/glass fiber reinforced epoxy composites, confirming that the presence of carbon fiber enhances mechanical performance in hybrid configurations.

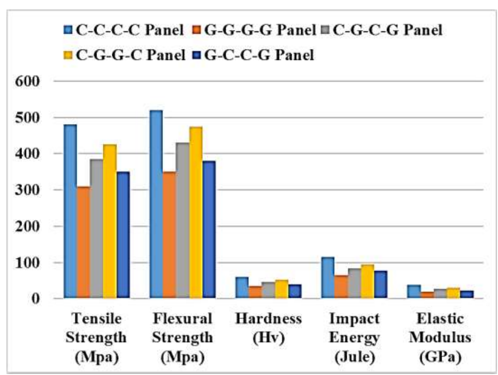

Figure 4: Effect of fiber layer alteration on mechanical performance

4. CONCLUSION

Altering fiber layer configurations significantly improves various mechanical properties of Composite panels, including tensile strength, flexural strength, hardness, impact energy, and elastic modulus. The following conclusions are drawn from the experimental work:'

1. Composite panels were made using the VARTM technique, with different fiber layer configurations (C/C/C/C, G/G/G/G, C/G/C/G, C/G/G/C, and C/G/G/C). Panels with the same fiber type had lower void content compared to those with different fiber types.
2. Tensile Strength: The C/C/C/C panel had the highest tensile strength (480 MPa), while the G/G/G/G panel had the lowest (310 MPa).
3. Flexural Strength: The C/C/C/C panel showed the highest flexural strength (520 MPa), and the G/G/G/G panel had the lowest (350 MPa).
4. Hardness: The C/C/C/C panel achieved the highest hardness (60 HV), while the G/G/G/G panel had the lowest (35 HV).'
5. Impact Energy: The C/C/C/C panel displayed the highest impact energy (115 J), with the G/G/G/G panel showing the lowest (65 J).
6. Elastic Modulus: The C/C/C/C panel had the highest elastic modulus (38 GPa), and the G/G/G/G panel had the lowest (20 GPa).

5. REFERENCES

[1] Gautam, V., & Nuwal, R., An Experimental Study Carried on Rotary Ultrasonic Machining on Fiber Reinforced Polymer Composites, SKIT Research Journal, 2021; 11(2): 71–76.

[2] Mitharwal, G., Srivastav, A., Kumar, D., Gautam, V., & Kumar, V., An Experimental Investigation of Rotary Ultrasonic Machining and Mechanical Property Evaluation on Hand Layup Fabricated Hybrid Composite, EVERGREEN, 2023; 10(4): 2599–2606.

[3] Gautam, V., Kumar, D., Kumar, A., & Pawar, M. J., Investigation on dry abrasion wear of natural and synthetic fiber reinforced polymer composites filled with stone waste, Materials Today: Proceedings.

[4] Tüzemen, M.Ç., Evaluation of tensile properties on glass/carbon fiber epoxy pure, interply, and locally nested intraply hybrid composites, Polymer Composites, 2022; 43: 6464–6475.

[5] Czél, G., Development of bi-directional pseudo-ductile glass/carbon-epoxy hybrid composites for improved safety in structural applications, Composites Part B: Engineering, 2022; 231: 109546.

[6] Subadra, S. P., & Griskevicius, P., Effect of hybridization and ply waviness on the flexural strength of polymer composites: an experimental and numerical study, Polymers (Basel), 2022; 14: 7.

[7] Lyu, Q., Wang, B., Zhao, Z., et al., Damage and failure analysis of hybrid laminates with different ply-stacking sequences under low-velocity impact and post-impact compression, Thin-Walled Structures, 2022; 180: 109743.

[8] Swolfs, Y., Gorbatikh, L., & Verpoest, I., Fibre hybridisation in polymer composites: a review, Composites Part A: Applied Science and Manufacturing, 2014; 67: 181–200.

[9] Naito, K., Static and fatigue tensile properties of carbon/glass hybrid fiber-reinforced epoxy composites, Scientific Reports, 2022; 12: 6298.

[10] Pandya, K. S., Veerraju, C., & Naik, N. K., Hybrid composites made of carbon and glass woven fabrics under quasi-static loading, Materials & Design, 2011; 32: 4094–4099.

[11] Zhang, J., Chaisombat, K., He, S., et al., Hybrid composite laminates reinforced with glass/carbon woven fabrics for lightweight load bearing structures, Materials & Design, 2012; 36: 75–80.

[12] Idarraga, G., Jalalvand, M., Fotouhi, M., et al., Gradual failure in high-performance unidirectional thin-ply carbon/glass hybrid composites under bending, Composite Structures, 2021; 271: 114128.

[13] Badie, M. A., Mahdi, E., & Hamouda, A. M. S., An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft, Materials & Design, 2011; 32: 1485–1500.

[14] Chen, D., Sun, G., Meng, M., et al., Flexural performance and cost efficiency of carbon/basalt/glass hybrid FRP composite laminates, Thin-Walled Structures, 2019; 142: 516–531.

[15] Damghani, M., Wallis, C., Bakunowicz, J., et al., Using laminate hybridisation (CFRP-GFRP) and shaped CFRP plies to increase plate post-buckling strain to failure under shear loading, Thin-Walled Structures, 2021; 162: 107543.

[16] Khan, T., Fikri, A., Irfan, M. S., et al., The effect of hybridization on microstructure and thermo-mechanical properties of composites reinforced with different weaves of glass and carbon fabrics, Journal of Composite Materials, 2020; 55: 1635–1651.

[17] Ribeiro, F., Sena-Cruz, J., Branco, F. G., et al., Analytical hybrid effect prediction and evolution of the tensile response of unidirectional hybrid fibre-reinforced polymers composites for civil engineering applications, Journal of Composite Materials, 2020; 54: 3205–3228.

[18] Katnam, K. B., Comer, A. J., Roy, D., et al., Composite repair in wind turbine blades: an overview, Journal of Adhesion, 2015; 91: 113–139.

[19] Chen, X., Experimental observation of fatigue degradation in a composite wind turbine blade, Composite Structures, 2019; 212: 547–551.

[20] Zuo, Y., Montesano, J., & Singh, C. V., Assessing progressive failure in long wind turbine blades under quasi-static and cyclic loads, Renewable Energy, 2018; 119: 754–766.

[21] Zamani, P., Jaamialahmadi, A., da Silva, L. F. M., et al., An investigation on fatigue life evaluation and crack initiation of Al-GFRP bonded lap joints under four-point bending, Composite Structures, 2019; 229: 111433.

[22] Ullah, H., Ullah, B., & Silberschmidt, V. V., Structural integrity analysis and damage assessment of a long composite wind turbine blade under extreme loading, Composite Structures, 2020; 246: 112426.

[23] Demir, O., Yar, A., Eskizeybek, V., & Avcı, A., Combined effect of fiber hybridization and matrix modification on mechanical properties of polymer composites, Proceedings of the IMechE Part L Journal of Materials: Design and Applications, 2023; 237(9): 1935-1951.