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Effect of Stacking Sequence on the Flexural Behavior of Glass/Kevlar Intralayer Hybrid Laminates

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ABSTRACT: This study investigated the mechanical properties of three samples of intralayer hybrid composite materials, manufactured using a hand layup technique. The composites were reinforced with glass and Kevlar fibers in various stacking sequences and fiber orientations: GK1 with (0°,90°)2s(0°, 90°)_{2s}(0°,90°)2s, GK2 with (+45°,−45°)2s(+45°, -45°)_{2s}(+45°,−45°)2s, and GK3 with (0°,+45°,90°,−45°)s(0°, +45°, 90°, -45°)_s(0°,+45°,90°,−45°)s. The focus of this work is on static mechanical properties, specifically three-point bending tests. The results from the static tests indicated that sample GK1 exhibited the best flexural properties among the three manufactured samples. These findings suggest potential applications for such hybrid composites in structural components, such as the wing skins of stealth aircraft and drones.

KEYWORDS: Glass/Kevlar hybrid composites; intralayer laminates; stacking sequence; fibre orientation

I. INTRODUCTION

An Composite materials combining two or more fiber reinforcements have become a focal point of research in aerospace and automotive industries, particularly where high strength-to-weight ratios are essential. Hybrid composites composed of glass and Kevlar fibres represent a promising material system, with glass fibres contributing stiffness and compressive strength, while Kevlar fibres provide toughness, impact resistance, and crack arresting capability [1,2]. Such synergy makes them particularly suitable for structural panels subjected to bending loads.

Previous works have emphasized the importance of fiber orientation and stacking sequence in determining flexural properties. Siyal et al. [3] studied the adhesion and mechanical behavior of glass–Kevlar laminates, highlighting the role of resin-to-hardener ratios. Kantrikar et al. [4] demonstrated that glass/Kevlar laminates with 0° and 90° orientations achieve higher flexural strengths compared to ±45° laminates. Similarly, recent findings by Suresh et al. [5] revealed that intralayer hybrid composites oriented at 0° fibers exhibited maximum modulus under bending.

Other studies have explored the effect of stacking sequence. For example, Ramakrishna et al. [6] reported that placing stiffer fibers such as glass on the outer layers while keeping Kevlar near the core enhances flexural resistance. Similar observations were made by Jayaraman and colleagues [7], who studied hybrid Kevlar/carbon/glass laminates and concluded that stacking sequence significantly controls damage initiation under bending. More recently, Gopinath et al. [8] showed that Kevlar/glass hybrids offered superior energy absorption compared to pure glass laminates under static loading.

Flexural behavior is also influenced by interlaminar shear strength (ILSS) and fibre–matrix bonding. According to Rajeshkumar et al. [9], interlaminar delamination plays a critical role in determining ultimate bending strength in hybrid laminates. Furthermore, Amuthakkannan et al. [10] found that hybridization can delay crack propagation and improve post-failure behaviour. Studies in aerospace composites [11,12] suggest that Kevlar/glass hybrids are increasingly investigated for UAV wing skins and lightweight structural covers, where bending and impact resistance are both critical. A recent review by Das and Rout [13] reinforced the consensus that hybridization is an effective strategy for tailoring flexural response without significant weight penalty.

In this context, the present work focuses on the fabrication of three intralayer hybrid composite laminates using a hand layup process with different stacking sequences: GK1 (0°,90°)2s(0°, 90°)_{2s}(0°,90°)2s, GK2 (+45°,−45°)2s(+45°, -45°)_{2s}(+45°,−45°)2s, and GK3 (0°,+45°,90°,−45°)s(0°, +45°, 90°, -45°)_s(0°,+45°,90°,−45°)s. Three-point bending tests were carried out according to ASTM D790 standard. Experimental details such as sample preparation, curing, and test parameters are to be reported in the methodology section. Results, including load–deflection curves, flexural modulus, and failure modes, will be presented in the results section.

II. MATERTIALS &METHODS

In this chapter show experimental work involved materials used , fabrication process and laboratory testing.

1- Materials:

In this study materials used are as the following:

Sample NO	Designations	stacking sequence of layers
1	GK1	$(0/90)_{2s}$ symmetric
2	GK2	$(+45/-45)_{2s}$ symmetric
3	GK3	$(0°/45°/90°/45°)_s$ symmetric

Table Error! No text of specified style in document.**-2 stacking sequence and Designations of samples**

1) E-glass /Kevlar hybrid fabric plain woven reinforcement.
2) Epoxy resin thermoset matrix.

Kevlar plain fibers reinforcement:

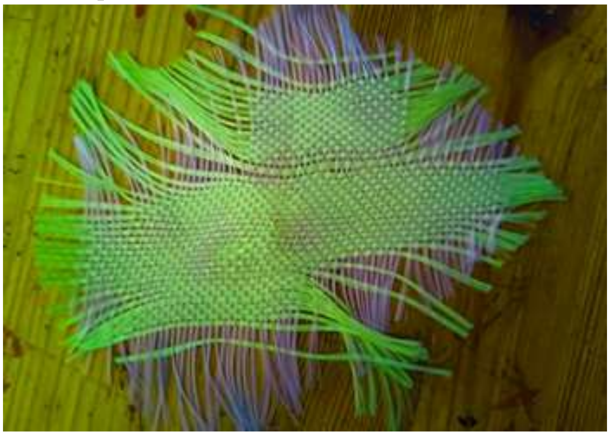

Figure 1 :Glass Kevlar hybrid fabric plain woven

a. Thermoset Epoxy Matrix:

Epoxy cast decoration was chosen as a matrix for composite laminate ,specification of resin given by supplier shown in table 1 below

Specification Property:

Table -1 :Specification properties of epoxy cast decoration

Specification	Value
Color	Crystal Clear
Solids by weight (%)100%	(±1%)
Flash point	100 °C./212°F.
Mixing ratio	(75 A: 25 B) by weight (gram scale required).
Pot Life	5 hour(s) 23°C/73°F

2- Fabrication of specimens:

Three samples were fabricate with different stacking sequence each sample have eight plies hybrid glass/Kevlar by different plies angles in epoxy resin as matrix The fiber was cut at the required angles using a laser cutter , all specimens fabricate by hand lay up technique were Laying the fiber with the required stacking and using the roller to impregnation with resin and applying pressure manually to remove air bubbles. The treatment was done at room temperature for an 48hours. the first specimens is$(0,90)_{2s}$ symmetric and the second is $(+45,-45)_{2s}$ symmetric and last is $(0°,45°, 90°, 45°)_s$ symmetric , All samples were processed at Safat Aviation Complex.

3- Preparation of specimen:

All specimen prepared according to ASTM standard, cutting by hand cutter the dimensions of all test showing in table below

Table -3 :Dimensions of tests specimens

Specimens Types and specification						
Unit	Flexural test			Impact test		
	GK1	GK2	GK3	GK1	GK2	GK2
Length (mm)	79	81	85	150	150	150
Width (mm)	13	13	13	100	100	100
Thickness (mm)	2.12	2.09	2.22	2.12	2.09	2.22

Figure Error! No text of specified style in document.**-2 Specimens for bending test**

Figure-3 Specimens for drop weight test

4- Laboratory testing:

Flexural properties of hybrid composite: The flexural properties of samples were determined by ASTM D790 protocols, The tests were performed in the ZWICK/ROELL (ZWICK Z010) machine showing in figure 3.6 as The applied velocity is 3.2mm/min the specimen dimensions are listed in Table 3.3, load–displacement plots were obtained for each test specimen, and three specimens of each type of composite were tested to get the average.

Figure -6 :Specimen under three -point bending test

III.RESULTS AND DISCUSSION

4.1 Flexural Test (static test) :

Three bending or flexural test were being performed by ASTM D790 for GK1&GK2 specimens and by ASTM D7264 for GK3 in order to obtain flexural properties the table 4.1 showed the flexural strength properties for all specimens and others flexural properties showed in table 4.3 for GK1 and GK2 and table 4.4 for GK3 .

Table Error! No text of specified style in document. **:Flexural strength of the specimens from the test**

Sample	Test number	Flexural strength value(MPA)
GK1	S1	189.74
	S2	174.48
	S3	203.38
Average		189.20
GK2	S1	52.35
	S2	46.08
	S3	56.26
Average		51.56
GK3	S1	148.46
	S2	151.78
	S3	170.28
Average		156.84

Table Error! No text of specified style in document. **:Flexural properties obtained from the test for(GK1&GK2)**

Property	GK1	GK2
Flexural modulus EH(GPa)	10.93	5.73
Flexural strain at breack ƐB (mm)	12.77	16.92
Flexural stress at breack σfB (N)	71.48	47.66
Maxium fracture strain ef(mm)	12.77	16.74

Table 5: Flexural properties obtained from the test for(GK3)

Property	Value
Deformation ε_{eM} (mm)	11.01
Maxium force σ_{fM}(N)	156.84
Young modulus Ef(MPA)	18629.95
Young modulus end σf'' (MPA)	44.96
Young modulus begin σf' (MPA)	7.70

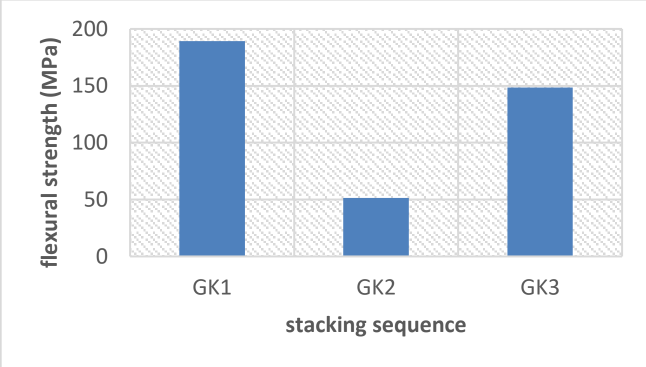

Figure -9 :stacking sequence of three samples GK1,GK2,GK3 and flexural strength

From the results showed above it is revealed that of the specimen GK 1 $(0,90)_{2s}$ staking sequence has higher flexural strength and maximum force prior to failure. The flexural strength value of GK1 higher by 20% compared GK3 and 270%compared to GK2 due to the shape of angles of the specimen GK1.

The value of flexural strength of GK1 is slightly less than the value obtained by (Nabeel et al., 2020) work when are made inter layers hybrid Kevlar glass samples For the same number of layers.

The load displacement curve for all specimens showing in figures below for GK1,GK2 and GK3 respectively .

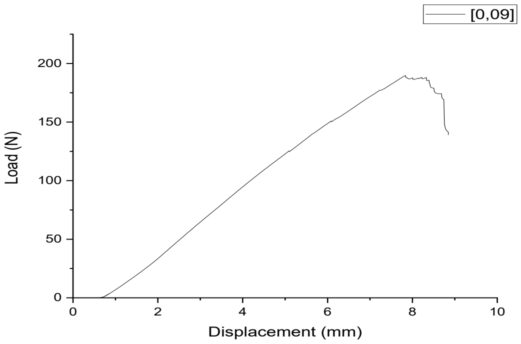

Figure -7 :The Load- Displacement curve from bending test for GK1

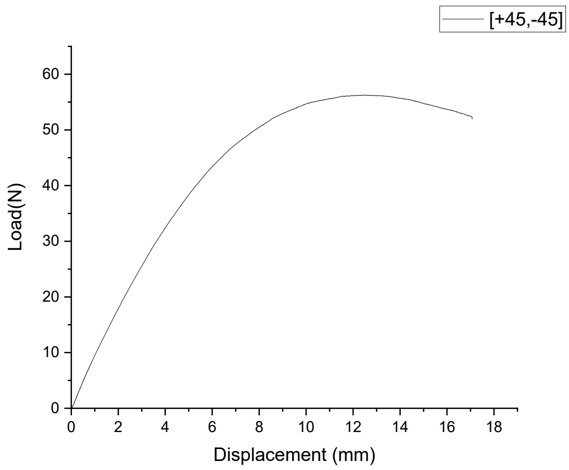

Figure --8 :The Load- Displacement curve from bending test for GK2

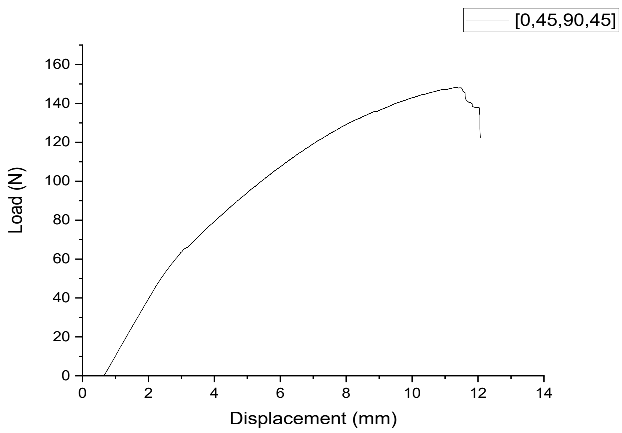

Figure -10 :The Load- Displacement curve from bending test for GK3

Failure mode:

By visual observation the types of failure are delamination and buckling.

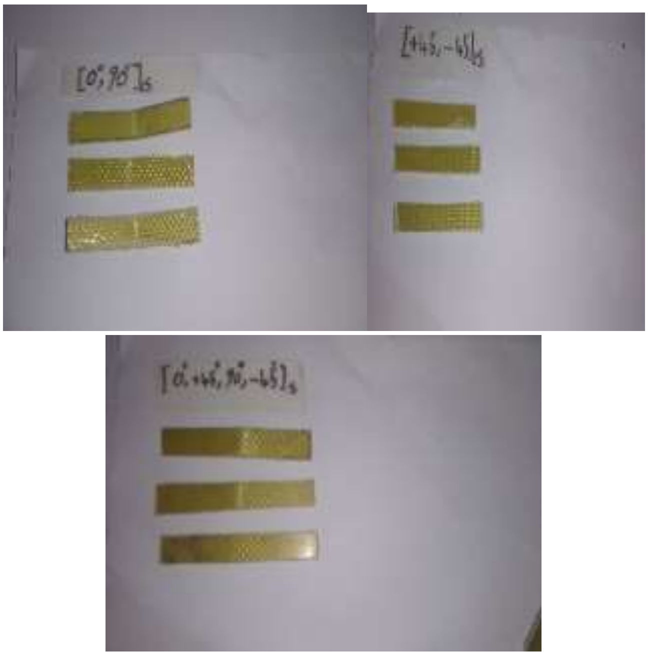

Figure-11 :Specimens after bending test

IV. DISCUSSION

The results of the three-point bending tests clearly demonstrate that stacking sequence and fiber orientation play a critical role in the flexural performance of Glass/Kevlar intralayer hybrid laminates. Among the three configurations, **GK1 (0°/90°)2s** exhibited the highest flexural strength with an average value of **189.20 MPa**, followed by GK3 (**156.84 MPa**), whereas GK2 (+45°/−45°)2s recorded the lowest strength (**51.56 MPa**). This indicates that the 0°/90° orientation significantly enhances load-bearing capability, while ±45° orientation is less effective in resisting bending stresses.

The superiority of GK1 can be attributed to the alignment of fibers along the principal loading direction, which ensures efficient stress transfer and minimizes shear deformation. In contrast, the low performance of GK2 may be explained by fiber misalignment under bending loads, leading to premature shear failure and delamination.

Interestingly, GK3, with a quasi-isotropic stacking of (0°/+45°/90°/−45°)s, provided intermediate performance between GK1 and GK2. Although not as strong as GK1, GK3 showed better energy absorption and progressive failure, suggesting that it may be more suitable for applications where both stiffness and impact resistance are required.

Flexural modulus results also supported these trends. GK1 showed the highest modulus (10.93 GPa), nearly double that of GK2 (5.73 GPa), indicating greater resistance to deformation. GK3 exhibited an intermediate modulus consistent with its mixed fiber orientation. The differences in strain at break further highlight the influence of stacking sequence: GK2 specimens displayed higher strain before failure, suggesting greater ductility but at the expense of strength, while GK1 specimens failed at lower strain, indicating higher stiffness but less energy dissipation.

Failure analysis revealed that delamination and local buckling were the dominant failure modes across all samples, with GK2 showing earlier onset of delamination. The relatively improved post-failure behavior of GK3 further suggests that hybridization at multiple angles delays crack propagation and distributes stresses more evenly.

When compared with previous works, the average flexural strength of GK1 (189.20 MPa) was slightly lower than the values typically reported for similar hybrid laminates, possibly due to differences in fiber volume fraction, curing conditions, or resin properties. Nonetheless, the experimental trends in this study confirm that placing glass fibers in the load direction significantly enhances stiffness and strength, while Kevlar contributes to toughness and impact resistance. Overall, these results confirm that GK1 stacking (0°/90°)2s provides the best combination of strength and stiffness, while GK3 offers a compromise between strength and energy absorption, and GK2 is less effective for flexural applications. Such insights are valuable for tailoring hybrid composites in aerospace and UAV structures, where lightweight materials with optimized stiffness and controlled failure behavior are crucial.

V. CONCLUSION

The reviewed literature indicates that both stacking sequence and fiber orientation have a decisive effect on flexural performance of glass/Kevlar hybrids. This study contributes by experimentally comparing three specific intralayer configurations. Preliminary results confirm that GK1, aligned with 0°/90°, provides the best flexural strength, consistent with trends reported in previous works. The findings open potential for applications in lightweight aerospace structures such as UAV and stealth aircraft wing skins.

REFERENCES

1. Agarwal, B.D., Broutman, L.J., Chandrasekhar, K. *Analysis and Performance of Fiber Composites*, Wiley, 2018.
2. Mallick, P.K. *Fiber-Reinforced Composites: Materials, Manufacturing, and Design*, CRC Press, 2021.
3. Siyal, S.H., et al. "Mechanical Characteristics and Adhesion of Glass-Kevlar Hybrid Composites." *Coatings*, 11(1), 94, 2021.
4. Kantrikar, A., et al. "Investigation of Flexural Properties of Glass-Kevlar Hybrid Composite." *EJEng Tech Res.*, 2020.
5. Suresh, G., et al. "Effect of Fiber Orientation on Mechanical Properties of Glass/Kevlar Epoxy Composites." *Polymers*, 13(16), 2591, 2021.
6. Ramakrishna, S., et al. "Effect of Stacking Sequence on Hybrid Composites under Flexural Loads." *Compos. Struct.*, 252, 112701, 2021.
7. Jayaraman, K., et al. "Flexural and Impact Properties of Kevlar/Carbon/Glass Hybrid Composites." *Mater. Today Proc.*, 43, 2021.
8. Gopinath, G., et al. "Comparative Flexural Performance of Glass and Kevlar Reinforced Epoxy Composites." *J. Mater. Res. Technol.*, 12, pp. 1456–1466, 2021.
9. Rajeshkumar, L., et al. "Interlaminar Shear and Flexural Strength of Glass/Kevlar Hybrid Composites." *Mater. Des.*, 200, 109444, 2021.
10. Amuthakkannan, P., et al. "Damage Tolerance of Kevlar/Glass Reinforced Epoxy Composites under Bending." *Adv. Compos. Mater.*, 30(2), 123–134, 2021.
11. Zhang, Y., et al. "Hybrid Fiber Composites for UAV Wing Skins." *Aerospace Sci. Technol.*, 118, 107056, 2021.
12. Li, H., et al. "Flexural Behavior of Kevlar-Glass Hybrid Laminates in Aerospace Applications." *Compos. Part B Eng.*, 230, 109508, 2022.
13. Das, S., Rout, A.K. "Review on Mechanical Behavior of Glass/Kevlar Hybrid Composites." *J. Reinforced Plastics and Composites*, 41(3), 123–140, 2022.