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Mechanical Characteristics of Hybrid Kevlar/Carbon Reinforced Polyester Composites

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Abstract: Current paper studied the effect of fiber configurations on the mechanical properties of hybrid composites. Kevlar-carbon /polyester hybrid composites with diverse fiber configurations were prepared by hand lay-up method. The incorporation between carbon and Kevlar fibers lead to an improvement in the mechanical strength and biodegradability of polyester composites. Experimental tests were carried to determine the mechanical characteristics like tensile, inter-laminar shear strength and flexural strength. The results obtained show the carbon reinforced polyester composites with configurations [5C] has the best mechanical properties compared to other laminates. The value of tensile strength of carbon composites with configurations [5C] was increased 2.18 times the value of Kevlar composites with configuration [5K]. While the carbon fabrics are put at the outer face and the core between the Kevlar fabrics layers, this is leads to the enhancement in tensile, flexural, and ILSS of Kevlar composite laminates, by ratio 40%, 37% and 30%, respectively. For scanning electron microscope (SEM) images, the hybrid composite laminates with configuration [C/K/C/K/C] demonstrated a good bonding between the fibers and matrix than that hybrid composite laminates with configuration [K/C/K/C/K]. These results show the potential of hybrid Kevlar/Carbon reinforced polyester composites for effective applications

1. Introduction

Composites are two or more physical & chemically different constituents combined to provide a useful material. Composite are divided in two groups namely composite made of artificial fibers and natural fibers (Gay et al., 2021and Al-Furjan et al., 2022). The synthetic fibers include carbon, glass, and Kevlar. The artificial fibers have high strength and stiffness. Kevlar fiber has low weight, high tensile strength, and high energy absorption. Kevlar fiber is five times better than that the steel due to its specific weight ratio. Kevlar is a type of aramid fibers and used in helmets, bulletproof vests and fuel tank. Also, it has improved interfacial fracture toughness and degree of symmetry in its internal structure (Mochalova et al., 2021and Zhou et al. 2022). Carbon fiber has a high-strength, lightweight and high temperature and corrosion resistance (Naresh et al., 2018 and Schmidt et al. 2017). Hybrid composites are consisting of two or more distinct materials combine in a single matrix. Hybrid composites have applications in various areas attributed to their favorable properties compared to the conventional composites (Prabhuram et al., 2010 and El-wazery et al. 2017, Al-Furjan et al. 2022, Mohamed et al. 2017). The effect of stacking sequence of carbon/ Kevlar/ S-glass hybrid composites on the mechanical behavior was studied. Flexural strength of glass/Kevlar hybrid laminates gave good hybrid effect, leads to 78 % increase relative to full Kevlar/epoxy composites (Bulut et al., 2017) In addition, the influence of hybridization by Kevlar/ carbon/glass fabrics reinforced epoxy composites on wear properties by Kartal and Demirer (Kartal et al., 2017) The carbon fabric reinforced epoxy composite gave the highest wear resistance. Wear resistance of Kevlar reinforced composites was lowering compared to both glass and carbon reinforced composites.

(Sandesh et al., 2016) demonstrated the tensile and flexural behavior of hybrid Glass/Kevlar fibers reinforced epoxy composites. Three types of hybrid composites with diverse stacking sequences have prepared. The hybrid composite with one-on-one layers gave the maximum value for tensile strength compared to other specimens. Also, the hybridization by using the Kevlar and E-glass fabrics stacked with epoxy are studied by (Jogi et al., 2017), the impact strength, and break resistance was investigated. E-glass/Kevlar at layup 0°/90°and 30°/60°orientation exhibited enhanced impact strength than 45°/45° orientation. The fracture study demonstrated that at 0°/90° orientation has better fracture strength compared to other orientations. The mechanical properties of the hybrid carbon-glass/epoxy composites were investigated. The carbon composite gives maximum hardness than those other hybrid composites (Jagannatha et al., 2015) Stephen et al. (Stephen et al., 2021) studied the energy absorption of the hybrid (Kevlar/ carbon/ glass) fabric reinforced epoxy composite laminates. Specimens consist of carbon layers in the middle; placed by Kevlar layers at the bottom and top (K/C/K) gave best energy absorption than that the other laminates. Effect of layers structure on the thermal and mechanical characteristics of hybrid bacterial cellulose sheet/Kevlar reinforced composites was demonstrated (Rusdi et al., 2022) High tensile stress for the BC sheets with 167.64 MPa and a Young's modulus of 12.78 GPa. El-wazery (EL-Wazery et al., 2018) studied the effect the stacking sequences on the mechanical properties and microstructure of carbon/basalt hybrid composites. A higher flexural and tensile property was found for the [C/B/C/B/C] hybrid composites. The main target of this paper was studied the influences of fiber configurations of hybrid composites reinforced with Kevlar, carbon fabrics processed by the hand layup on the microstructure and mechanical properties of hybrid composites.

2. Experimental work

2.1. Hybrid composites processing

Hand layup procedure was used to manufacture the polyester hybrid composites with Kevlar, Carbon fabrics. Bi-directional woven Kevlar (biaxial weave 190 g/sqmt.) and carbon fabric twill weave (C120-3K-Twill 2x2), were utilized as a reinforcement element. Unsaturated Polyester (ECMAS 411) as a matrix and ketone peroxide hardener (MEKP) is used to fabricate the material. Table 1 shows the mechanical and physical properties of the carbon and Kevlar fabrics reinforcements (Lokesh *et al., 2019)* Photographic image of pieces of the Kevlar and carbon fibers are shown in Figure 1. More details about the hybrid composites fabrication *(EL-Wazery et al., 2017 El-Menshawy et al., 2019,)* Design structure of hybrid composite laminates is given in Table 2. Sample preparation of Kevlar-carbon /polyester hybrid composites with various fiber configurations are shown in Figure 2.

Table 1. Physical and mechanical properties of Kevlar, carbon and glass fabrics reinforcements (EL-Wazery et al., 2017)

Properties	Kevlar	Carbon
Density [g/cm^{-3}]	1.44	1.90
Fabric pattern	Bi-directional woven	Twill weave
Fabric thickness (mm)	0.25	0.30
Areal density (g/m^2)	190	200
Elastic modulus [GPa]	154	260
Elongation at break (%)	2.5	1.70
Impact strength	Excellent	Fair
Inter-laminar shear strength	Fair	Excellent

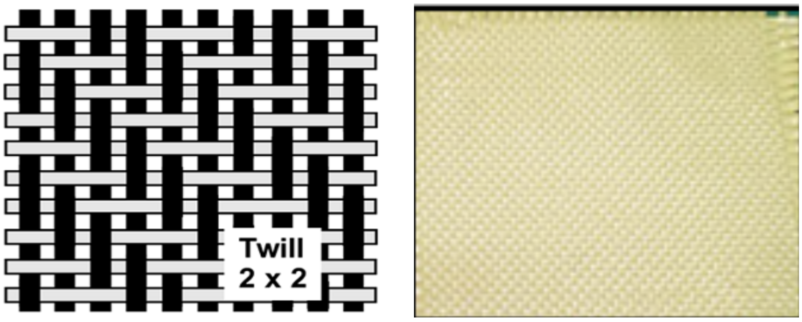

Figure 1. Photographic image of pieces of the fibers used
(a) Carbon fibers, (b) Kevlar fibers

Table 2. Designation of hybrid composite laminates and relative fabric weight and volume fractions

Code	Fiber configurations	Carbon contents (wt.%)	Kevlar Contents (wt.%)	Volume fraction (vt. %)		
				Polyester	Kevlar	Carbon
C1	[5C]	0	60	46.65	0	53.35
C2	[5K]	0	60	53.42	46.58	0
C3	[K/C/K/C/K]	12	48	44.46	33.88	21.66
C4	[C/K/C/K/C]	48	12	44.46	21.66	33.88

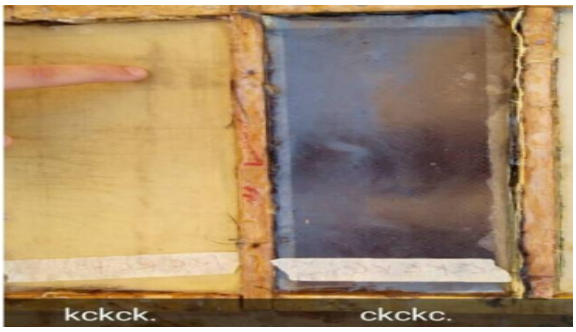

Figure 2. Sample preparation process of Kevlar-carbon/polyester hybrid composites

2.2. Mechanical characteristics

2.2.1. Tensile strength

The tensile test was conducted according to ASTM D 638. The tensile strength was analyzed by using INSTRON 8801 universal testing machine with a crosshead speed of 2 mm/min. Experimental setup for the tensile test as shown in Figure 3. The specimens were cut from the laminated composites using wheel saw and finished to the accurate size of 165 mm × 25 mm × 6 mm. Five specimens were tested and the mean value has been evaluated.

Figure 3. Experimental setup for the tensile tests

The tensile strength is determined by the **Eqn**. [1]

[1] $Tensile\ strength = \frac{F}{A}$

2.2.2. Flexural properties

Flexural strength and ILSS of the hybrid composites were measured according to ASTM D790-10. The dimensions of the specimens were 125 x 13 x 6 mm. five identical specimens were prepared and the average value was reported. The flexural strength and ILSS was determined by the **Eqn**. [2], and **Eqn**. [3] respectively [22].

$$Flexural\ \ strength = \frac{3fl}{2bd^2} \quad [2]$$

[3] $ILSS = 0.75\frac{f}{bd}$

While f, l, d, b and ILLS is the flexural load (N), the span (gauge), thickness (mm), the width (mm)

3. Results and Discussion

3.1 Tensile and flexural properties

Figure 4 (a, b) shows the load-displacement curves of the hybrid composite laminates with fiber configurations [5C], [C/K/C/K/C], respectively. For this combinations as shown in Figure 4(a, b), It was observed that the tensile load increase linearly, and it starts decreasing up to the fracture point. As the seen in Figure 4a, it is clear that the pure carbon composites with combination [5C] exhibited maximum force reach to 7500 N among the four different laminates. The tensile load withstanding capacity of the combinations [C/K/C/K/C] and [K/C/K/C/K] are 24% and 44%, respectively, which is lower than carbon composites with combination [5C][

The effect of the fiber configurations on the tensile strength and flexural properties of the Kevlar/carbon hybrid composites are shown in Figure 5 to Figure 7 and Table 3. The fibers configuration plays a main role in the hybrid composite to achieve desired results of tensile strength and flexural properties. As the seen in bare chart in Figure 5 and Table.4, it can be concluded that the pure carbon fabric reinforced polyester composites with combinations [5C] exhibited maximum tensile strength (96 MPa) among the four different laminates. It was attributed to the young modulus of carbon fiber is much higher than the Kevlar fiber. Also, the hybrid composite made out of carbon and Kevlar with fiber configurations [C/K/C/K/C] has higher tensile strength than that the other combinations [K/C/K/C/K], [5K] respectively.

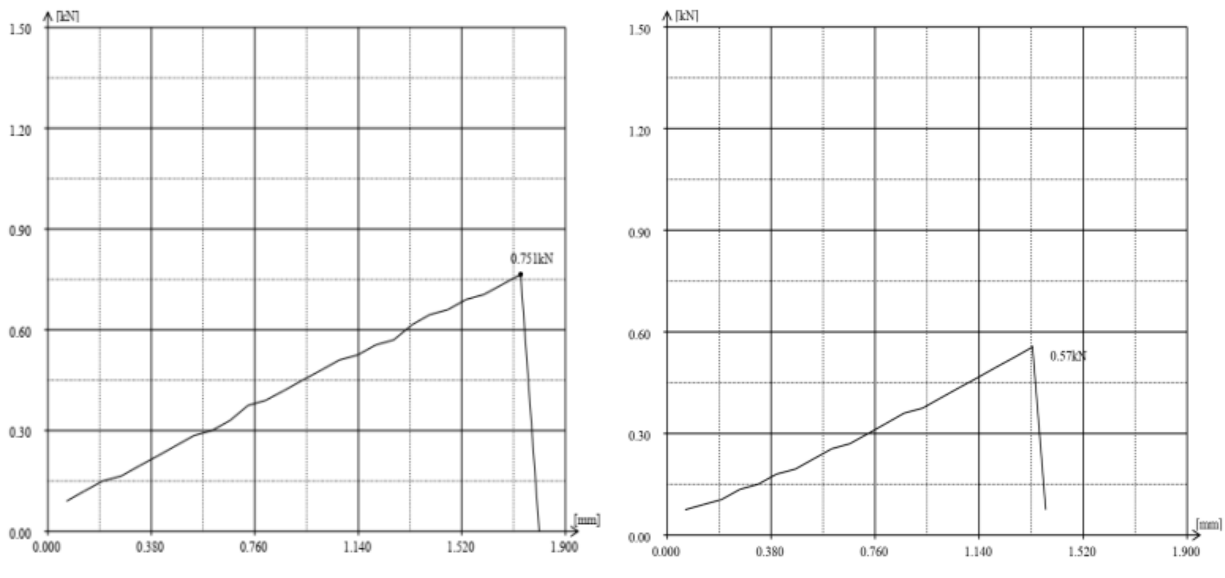

Figure 4. load displacement curves of hybrid composite laminates with fiber configurations a) [5C], b) [C/K/C/K/C]

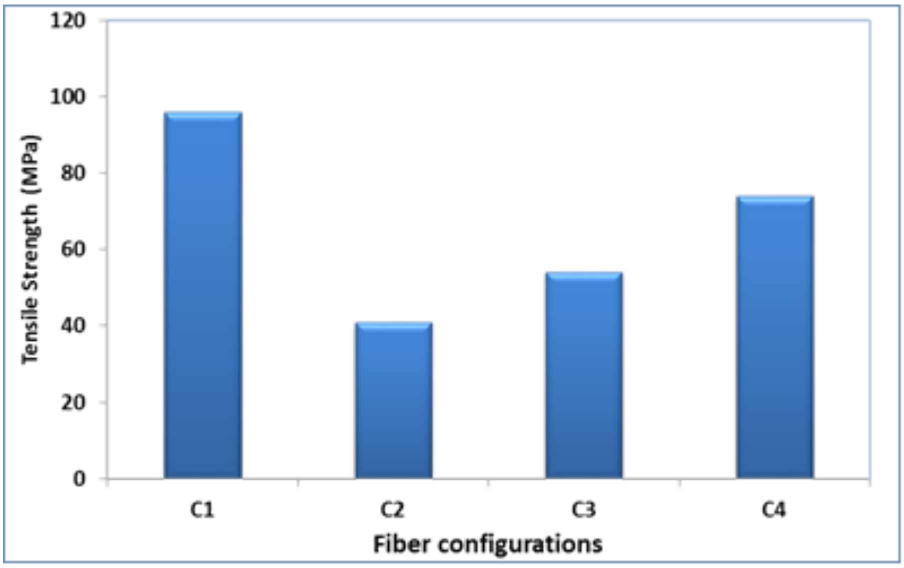

Figure 5. Tensile strengths versus fiber configurations

It was observed that from the bar chart in Figure 6 and Figure 7, the flexural strength and ILSS of the hybrid composites laminates are affect by the fiber configurations of the Kevlar and carbon fabrics. So, the hybrid composite with combination [C/K/C/K/C] has high flexural strength and ILSS than that the combination [K/C/K/C/K]. The flexural strength of the pure carbon and Kevlar composites with the combination [5C] and [5K] was 240 MPa and 150 MPa, respectively. This is because of the adhesion between the reinforcement layers in carbon fabrics are more than Kevlar fiber layers. This high adhesion in carbon fabrics enables better load transfer to the reinforcement. Whereas a poor interfacial bonding will be preventing adhesion between the resin matrix and fibers. In addition, the stiffness and strength are more for carbon composites than the Kevlar composites. As the seen in Figure 7, the ILSS of combination [5C] was increased by ratio 39% compared to the combination [5K]. Where the wettability of the carbon fabric is more than that of the Kevlar fabric, the resin has infused properly in between the carbon reinforcement layers more easily through the pores of the fiber layers.

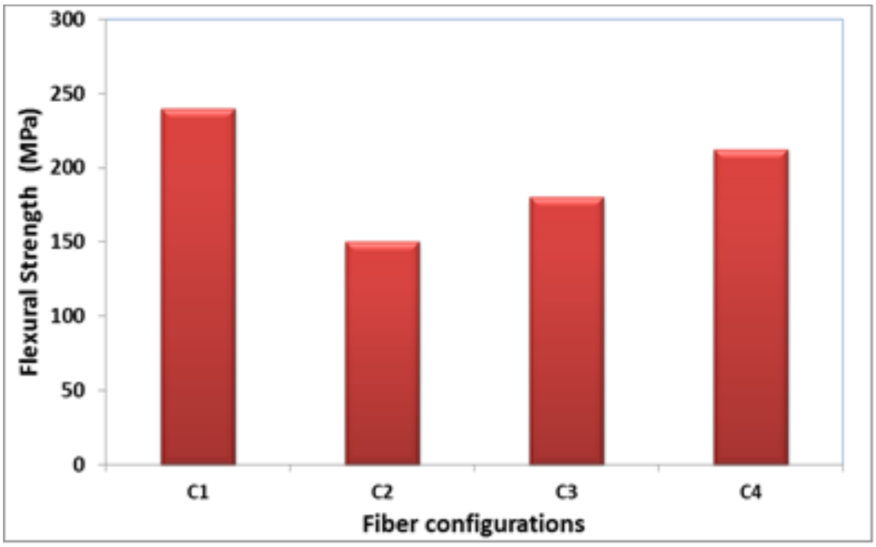

Figure. 6 Flexural strengths versus fiber configurations

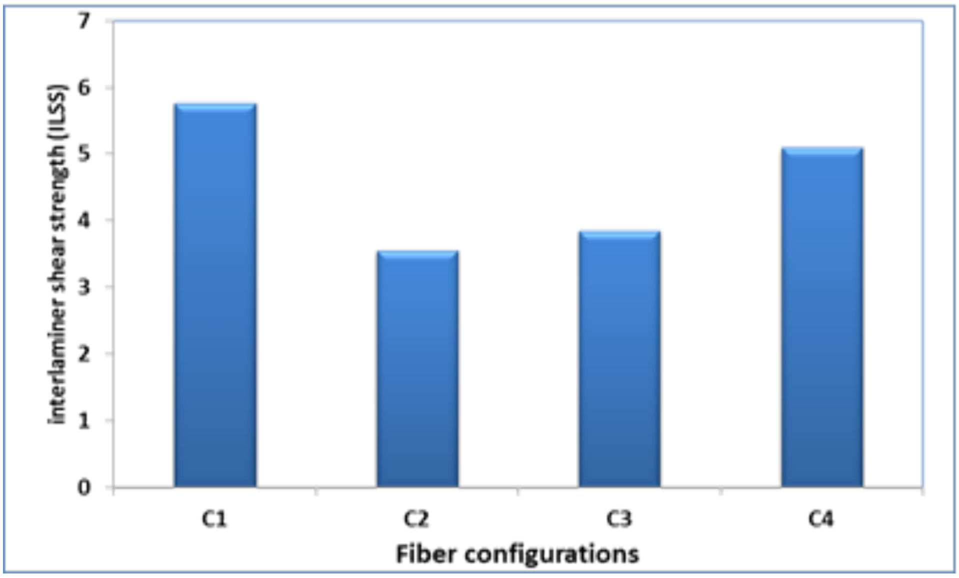

Figure. **7** Inter-laminar shear strength versus fiber configurations

Table 4 Tensile, flexural and ILSS properties of the hybrid composite laminates

Code	Combinations	Maximum Load (N)	Tensile strength (MPa)	Flexural strength (MPa)	Inter-laminer shear strength (ILSS) (MPa)
C1	[5C]	7500	96	240	5.76
C2	[5K]	3410	44	150	3.55
C3	[K/C/K/C/K]	4220	54	180	3.84
C4	[C/K/C/K/C]	5710	74	212	5.09

3.2 Microstructural analysis (SEM)

Microstructural analysis of the tensile fractured specimens was analyzed using SEM. Bonding between the fiber and matrix plays a main role in enhancement the mechanical characteristics of the hybrid composites. SEM images of the fractured surfaces of the tensile test failed Kevlar/Carbon hybrid composite with the combinations [C/K/C/K/C] and [K/C/K/C/K], respectively are shown in Figure 8a,b. As the seen in Figure 8a, there are Kevlar fiber pulled-outs, more delamination's between the Kevlar fabrics and shows the poor adhesion between the fiber and matrix. The poor fiber/matrix adhesion led to the decreasing in the tensile strength of this combination [K/C/K/C/K], where reached to 54 MPa. From Figure 8b, it is observed that understood that though the carbon fabrics have better bonding with the matrix and it has which affects the mechanical characteristics of the hybrid composites. As the result, the tensile strength and flexural properties of this combination[C/K/C/K/C] were enhanced, where reached to 74 MPa, 212 MPa, respectively.

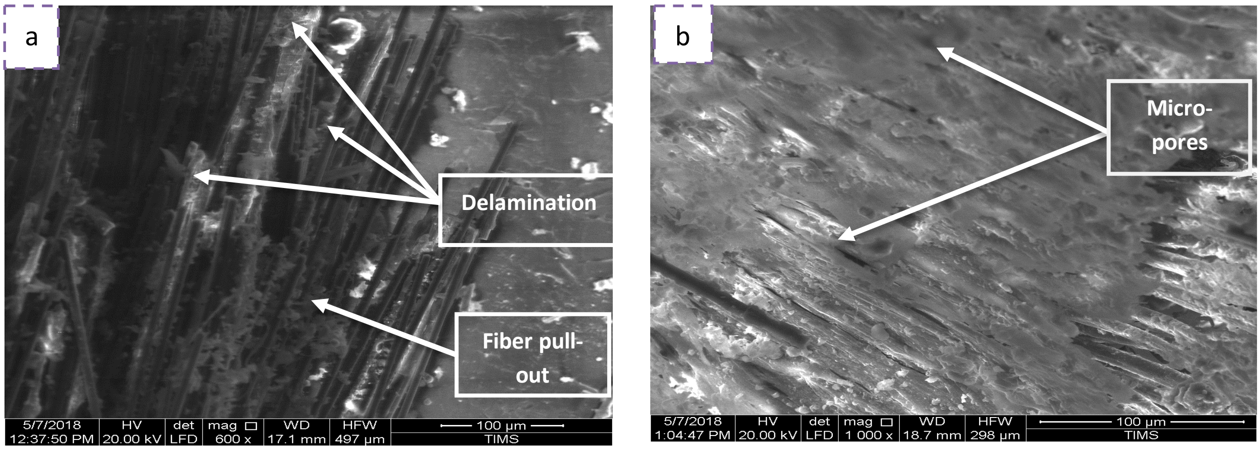

Figure 7. Fracture surface of the hybrid composites with combinations a) C3 [K/C/K/C/K] and b) C4 [C/K/C/K/C]

4. Conclusion

The present work is incurred to evaluate the mechanical properties of the hybrid Kevlar/carbon reinforced composites. Hybrid composites with different fiber configurations of carbon-Kevlar laminates specimens have been processed by using the hand layup procedure. After conducting various tests on the carbon-Kevlar hybrid composite following can be concluded:

- Highest tensile and flexural properties were observed in the carbon composite with combinations [5C] compared to other laminates.
- The hybrid composites with code C4 [C/K/C/K/C], can efficiently replace the pure Kevlar composites with code C2 [5K].
- Weak adhesion between the fiber and matrix for the combination [K/C/K/C/K], this is attributed to the Kevlar fiber pulled-outs and more delamination's between the Kevlar fabrics

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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