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Experimental Study on the Residual Property of Kevlar-Jute/Epoxy Hybrid Composite Laminates with Multiple Drilled Holes

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ABSTRACT

The study estimates the residual property of [Jute/Kevlar/Jute] and [Kevlar/Jute/Kevlar] hybrid composite laminates with multiple drilled holes. The laminates are prepared using a compression molding technique with Kevlar and Jute as reinforcements in two different stacking sequences. Post-fabrication, holes are drilled with two different center diameters 4 mm and 12 mm and multiple holes are drilled with two different effective lengths from the center hole, i.e. 2 mm and 4 mm. Compression testing is conducted using a Universal Testing Machine (UTM) to assess the compression strength of the specimens without drilled and with drilled specimens. The damage reduction factor, residual strength ratio, residual load carrying capacity and the effective stress post damage are then evaluated for the laminates with drilled holes at different effective lengths. The article is intended to suggest possible reduction in strength on introduction of natural fiber in an existing construction so that based on requirement, existing structures can be optimized. The study aims to measure the reduction in compressive residual strength due to stress concentrations introduced by drilling. Testing showed that the laminate configuration KK05 exhibited the highest residual compressive strength, retaining approximately 85% of its original strength after drilling, making it ideal for applications requiring high durability.

摘要

该研究估计了具有多个钻孔的[Jute/Kevlar/Jute]和[Kevlar/Jute/Kovlar]混合复合材料层压板的残余性能。层压板是使用压缩成型技术以凯夫拉纤维和黄麻作为增强材料，以两种不同的堆叠顺序制备的。制作后，钻取两个不同中心直径4 mm和12 mm的孔，并钻取多个距离中心孔两个不同有效长度的孔，即2 mm和4 mm。使用万能试验机（UTM）进行压缩试验，以评估无钻孔和有钻孔试样的抗压强度。然后，对不同有效长度钻孔的层压板的损伤折减系数、残余强度比、残余承载能力和损伤后的有效应力进行了评估。本文旨在建议在现有建筑中引入天然纤维可能会降低强度，以便根据要求优化现有结构。该研究旨在测量钻井引起的应力集中导致的压缩残余强度的降低。测试表明，层压配置KK05表现出最高的残余抗压强度，在钻孔后保持了约85%的原始强度，使其成为需要高耐久性的应用的理想选择。

KEYWORDS

Kevlar; Jute/Epoxy; drilling; compression molding; universal testing machine; critical hole tolerance; residual compressive strength

关键字

凯夫拉纤维; 黄麻/环氧树脂; 钻井; 压缩成型; 万能试验机; 临界孔公差; 残余抗压强度

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Introduction

The demand for lightweight, high-strength materials in industries such as aerospace, automotive, and marine has driven a surge in the development of fiber-reinforced composite materials (Aruchamy et al. 2023; Hosseini et al. 2023; Huang et al. 2023; Reddy et al. 2020; Singh, Dutt, and Hirwani 2022; Varga et al. 2010; Wei et al. 2018). Among these, hybrid composite laminates, which combine synthetic and natural fibers, have garnered significant interest due to their ability to offer a balance between performance and environmental sustainability (Hafez et al. 2024; Kenney et al. 2024; Li et al. 2024; Olonisakin et al. 2022). Kevlar-Jute/Epoxy composites, for example, integrate the high tensile strength and impact resistance of Kevlar with the eco-friendly and cost-effective properties of jute fibers, resulting in a versatile hybrid laminate suitable for structural applications. Kevlar and jute fibers, when combined with epoxy matrices, create composites with a unique blend of mechanical properties, making them suitable for structural applications where lightweight, high strength, and durability are critical (Park et al. 2002; Sangamesh, Ravishankar, and Kulkarni 2020; Sarwar et al. 2020; Suhad 2020; Nath et al. 2019).

However, the structural integrity of composite laminates is often compromised by machining processes, such as drilling, which are necessary for assembling and joining components. Drilled holes in composite materials introduce stress concentrations that can weaken the laminate and lead to a reduction in its load-bearing capacity. This is particularly critical in hybrid composites like Kevlar-Jute/Epoxy laminates, where the interface between natural and synthetic fibers may exhibit complex damage mechanisms under stress. Kumar et al. (2021), in their study, examined the joining feasibility of natural filler-reinforced polymer composites. They analyzed the adhesive, mechanically fastened, and hybrid joints' mechanical properties. Adhesive joints are found to be stronger than drilled holes, but drilling holes remains challenging in GFRP composites. Hybrid joints have similar mechanical properties but higher extension at the break. Also, Kumar et al. (2023) compared the mechanical properties of molded and drilled holes in jute-fiber-reinforced epoxy composites and found that molded holes perform better than drilled holes. The maximum tensile load taken by molded holes was 48.8% and 101.5% greater than drilled holes. Additionally, specimens with molded holes achieved a larger degree of extension compared to those with drilled holes. The study highlights the importance of molded holes in composite materials.

Kumar et al. (2012) investigated the drilling characteristics of glass fibre (GF)/vinyl ester composites, focusing on their superior mechanical and chemical properties. The study reveals the impact of drill geometry, cutting speed, and feed rate on drilling forces and surface roughness, with ANOVA analysis revealing the relative significance of these parameters. Understanding the residual mechanical properties of these laminates with multiple drilled holes is crucial for optimizing their performance in practical applications (Bhatia and Arockiarajan 2023).

Residual strength, defined as the remaining strength after damage or loading conditions such as drilling, is vital for assessing the durability of composites (Özdemir et al. 2022). Drilled holes in laminates introduce defects and stress concentrations, leading to a significant reduction in mechanical performance (Bisaria et al. 2015). Du, Yang, and Liu (2023) investigated the impact of drill bit geometry on drilling-induced damage in CFRP composites and found that tensile strength can decrease by up to 56.09%. Similarly, Hu et al. (2023) reported a 44.3% to 51.3% reduction in tensile strength for laminates with a 6.35-mm diameter hole, depending on the layup configuration. In natural fiber composites, such as kenaf and aloe vera, drilled holes can reduce the load-bearing capacity by 10.7% to 17.2% compared to molded holes (Rana et al. 2024). Singh and Samanta (2015) confirmed fiber rupture and fragmentation as significant damage mechanisms. Effective drilling, crucial for nut-bolt connections, can optimize thrust force, torque, and fiber architecture, contributing to circular economy goals.

This study aims to address the gap in understanding how drilled holes affect the residual strength of concentrations of Kevlar-Jute/Epoxy hybrid composite. While hybrid composites like Kevlar-Jute offer a promising balance of strength, sustainability, and cost-effectiveness, drilled

holes create stress that compromises their structural integrity. Although research on drilled holes in fully synthetic composites is extensive, few studies have focused on natural-synthetic hybrids like Kevlar-Jute. The natural fiber introduces unique issues – such as variations in fiber bonding and moisture absorption – that may further weaken the material around drilled areas. Understanding the residual strength of these composites after drilling is essential for optimizing designs, establishing safe machining practices, and validating the use of Kevlar-Jute for sustainable structural applications. This study, therefore, provides critical insights needed for the reliable and eco-friendly application of hybrid composites in engineering (Mahbub et al. 2014; McAllister, Gillespie, and VanLandingham 2012; Ozgul and Ozkul 2018; Sanjay, Arpitha, and Yogesha 2015; Thomason, Yang, and Meier 2014).

Material selection

The fibers selected for the fabrication are Kevlar and Jute fiber. Kevlar, developed by DuPont in 1965, is a strong synthetic fiber known for its high tensile strength-to-weight ratio, being five times stronger than steel by weight. It is widely used in bulletproof vests, helmets, ropes, cables, and tire reinforcements due to its excellent impact resistance, lightweight, flexibility, and resistance to heat and chemicals (Fatima and Mohanty 2011; Mir et al. 2010; Wang et al. 2019). Jute is a long, soft natural fiber extracted from the jute plant's bark, second only to cotton in global production. It is used in burlap, packaging, textiles, and sustainable products, valued for its biodegradability, insulating properties, and low thermal conductivity (Borah and Samanta 2022; Oliwa 2020). The material properties are represented in Table 1. Apart from Kevlar and Jute, resin used is epoxy LY556 and hardener HY 951 as shown in Figure 1 (Jin, Li, and Park 2015; Kocaman and Ahmetli 2016; Novák, Šimoníková, and Chodák 2001; Strzelec, Leśniak, and Janowska 2005; Tripathy et al. 2000). The material properties are presented in Table 2.

Table 1. Material properties of kevlar and jute.

Material	Kevlar	Jute
Density (g/cm ³)	1.44	1.3
Fibre diameter (microns)	10–12	17–20
Tensile strength (MPa)	2920	393–773
Elastic modulus (GPa)	70	13–26
Elongation at break (%)	3.6	1.5–1.8
GSM (g/m ²)	200	200



Figure 1. Kevlar, jute fibre, resin, and hardener.

Table 2. Material properties of epoxy resin and hardener.

Material	Viscosity at room temperature (MPa)	Density at room temperature (gm/cc)
Epoxy LY556	9000–12000	1.13–1.16
Hardener HY951	500–1000	0.946

Methodology

Fabrication of laminate

Kevlar-jute/epoxy hybrid laminates are fabricated using a 30 Tons Compression molding machine by G-Tech (Adin and Adin 2022; Doan, Brodowsky, and Mäder 2012; Yeung and Rao 2012). Kevlar and jute plies are arranged layer by layer with resin and hardener applied between them (Ashraf et al. 2019; Goud et al. 2022). The setup is cured at 45°C and 50 psi for 3.5 h. The process ensures even resin distribution and minimal voids. The description of stacking sequence is given in Table 3, and the pictorial representation of fabrication is given in Figure 2.

After fabrication, the laminate is cut into standard specimen sizes according to ASTM D7137/ D7137M standards, resulting in six specimens of 150 × 100 mm each. The test specimen dimension is presented in Figure 3.

Table 3. Description of laminate stacking sequence.

Sl. No.	Stacking sequence	Weight of fibres (gm)	Thickness (mm)	Notation
1	K-J-K-J-K-J	135	3.6	KJ type (Kevlar-Jute)
2	K-K-K-J-J-K-K-K	175	3.5	KK type (Kevlar-Kevlar)



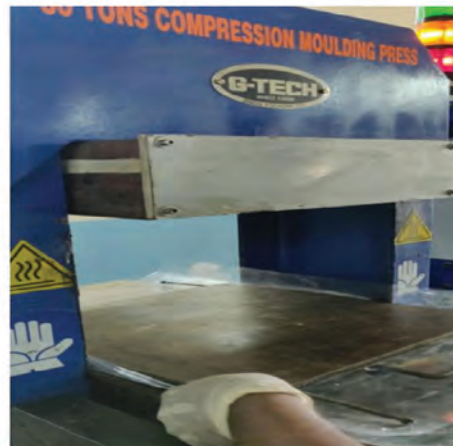
(a) Single ply arrangement on Fixture



(b) Epoxy resin application



(c) Layers Stacking



(d) Compression molding of the Laminate

Figure 2. Fabrication of laminate using compression moulding.

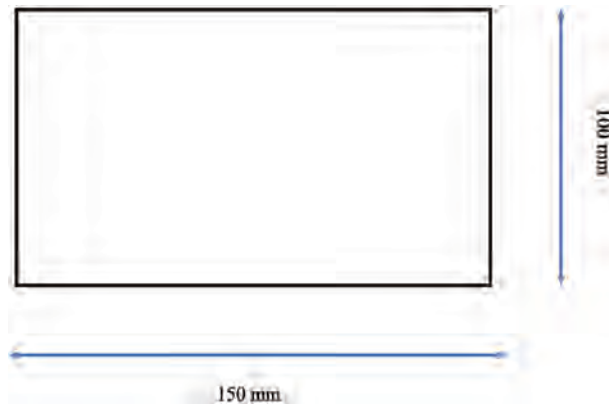


Figure 3. Specimen dimensions.

Process of drilling holes in laminate

Standard specimens are drilled using 4-mm and 12-mm bits for comparative studies. After checking the drilling machine, a 4-mm bit is fixed, and specimens are centered for drilling. Holes are drilled at 2-mm and 4-mm intervals from the center, then filed, punched to enhance size, and cleaned. The process is repeated with the 12-mm bit, and four undrilled specimens are retained for residual strength testing. Specimens are labeled by hole positions and dimensions. Figure 4 presents the drilling machine and the respective specimen.

Table 4 presents a detailed classification of Kevlar-Jute (KJ) and Kevlar-Kevlar (KK) composite laminate specimens prepared to study the effects of drilled holes on residual strength. Each specimen is categorized by type, including both KJ and KK composites, and whether it is undrilled

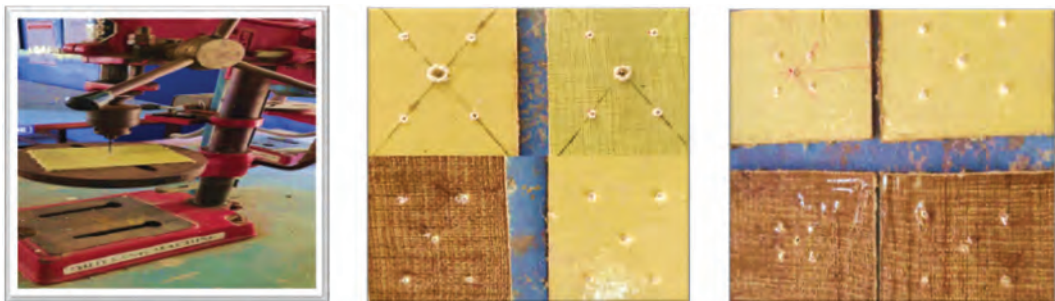


Figure 4. Drilling machine, specimen with 12-mm and 4-mm radius holes.

Table 4. Laminate configuration and drilled specification.

	Code	Type of specimen	Centre hole diameter	Effective length
KJ type	KJ01	Undrilled	Nil	Nil
	KJ02	Drilled	4 mm	2 mm
	KJ03	Drilled	4 mm	4 mm
	KJ04	Drilled	12 mm	2 mm
	KJ05	Drilled	12 mm	4 mm
KK type	KK01	Undrilled	Nil	Nil
	KK02	Drilled	4 mm	2 mm
	KK03	Drilled	4 mm	4 mm
	KK04	Drilled	12 mm	2 mm
	KK05	Drilled	12 mm	4 mm

or drilled with specified hole diameters and effective lengths. For Kevlar-Jute (KJ) specimens, KJ01 serves as an undrilled specimen, having no center hole or designated effective length. The drilled specimens vary in hole diameter and effective length around the hole. KJ02 and KJ03 feature a 4-mm diameter center hole with effective lengths of 2 mm and 4 mm, respectively, allowing for comparison of residual strength based on effective length for smaller hole sizes. KJ04 and KJ05, with larger 12-mm diameter center holes, also vary by effective lengths of 2 mm and 4 mm, enabling an assessment of how increased hole size and surrounding area impact the material's strength. Similarly, the Kevlar-Kevlar (KK) specimens include one undrilled specimen (KK01) and four drilled variants. KK02 and KK03 have a 4-mm diameter center hole with effective lengths of 2 mm and 4 mm, respectively, while KK04 and KK05 are drilled with a larger 12-mm hole diameter and effective lengths of 2 mm and 4 mm. This range of configurations allows for an in-depth analysis of how hole size and surrounding effective length impact residual strength in KK composites.

By drilling the holes in the specimens in a defined manner, the study can effectively compare undrilled and drilled configurations, assessing how drilled holes of different sizes and effective lengths affect the residual strength of each composite type. This proposed configuration of holes provides valuable insights into the structural reliability and behavior of Kevlar-Jute and Kevlar-Kevlar laminates under conditions where drilled holes are required.

Compression testing

Compression tests are conducted as shown in [Figure 5](#) on drilled specimens with varying diagonal hole lengths. Specimens are secured, and loads are applied, with load and CHT values displayed on a monitor. As the load increases, samples buckle, indicating their compressive strength. Peak load is recorded at the onset of buckling. Compressive strength is calculated using the formula:

Loads are taken from the testing results and peak loads are considered as compressive load, where

$$\text{Area under applied load} = \text{width} \times \text{thickness.} \quad (1)$$

Results and discussion

This section presents the experimental findings and interprets the results in the context of existing literature.

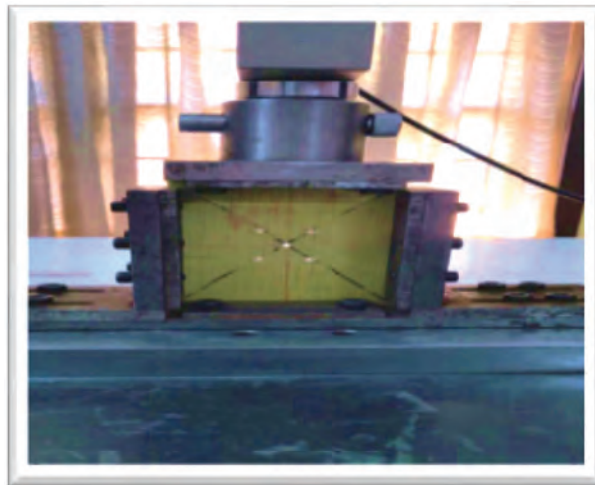


Figure 5. Specimen under testing.

Compressive strength for different laminate configurations

The compressive residual strength of the specimen is obtained through the testing of the specimen using a universal testing machine under compression loading. The universal testing machine has the output monitored, and the results are obtained after the testing of the standard test specimens. Following the UTM testing results, following tabulations and graphs are made. The compressive loads applied on the test specimen are noted, as well as the CHT values are noted and graphs are plot between load values and CHT values. Compressive strength of each specimen is calculated by the formula:

The data in Table 5 for Kevlar-Jute (KJ) and Kevlar-Kevlar (KK) hybrid composite laminates show notable differences in compressive strength and variability between the two types. The KJ specimens exhibit a wider range of compressive strength values, from 16.4 MPa to 34.4 MPa. In contrast, the KK specimens display compressive strength values ranging from 26.5 MPa to 38.8 MPa, indicating more consistent performance under compression. The observed fluctuations in compressive strength, particularly in the KJ specimens, can be attributed to several factors. First, the hybrid composition of the KJ specimens, which combines synthetic Kevlar and natural Jute fibers, likely introduces variability due to differences in bonding quality between these fiber types. Natural fibers like Jute are inherently more variable in terms of fiber density and orientation, resulting in uneven load distribution across the laminate (Elfaleh et al. 2023; Saba, Paridah, and Jawaid 2015). In contrast, the KK specimens, being composed solely of Kevlar fibers, benefit from a more uniform fiber–matrix interface, leading to higher strength consistency (Biruk-Urban et al. 2024). Additionally, the presence of multiple drilled holes introduces stress concentrations that may reduce compressive strength, with the degree of impact varying based on factors such as drilling precision and the exact location of the holes relative to fiber orientation. Minor differences in hole quality, such as slight misalignments or variations in diameter, could significantly affect certain specimens, particularly in the KJ laminates where natural fibers may be less able to withstand localized stresses (Jagadeesh et al. 2023; Karthik et al., 2020; Zarif Karimi et al. 2013). Lastly, variations in experimental conditions, such as slight misalignments during testing or sensitivity differences in equipment, could introduce additional fluctuations in compressive strength measurements. These combined factors – material composition, fiber orientation, manufacturing consistency, and environmental influences – likely account for the differences in compressive strength variability between KJ and KK specimens. The more consistent performance in KK specimens suggests that all-Kevlar laminates may offer greater reliability in applications requiring uniform strength.

Figure 6 illustrates the load-displacement relationship for five different samples (KJ01 to KJ05). KJ01 (black) reaches the highest peak load of approximately 13.8 kN at around 4.7 mm displacement, followed by KJ02 (red) with a peak load of about 11.8 kN at 4.4 mm. KJ03 (blue) shows a peak load of approximately 9.7 kN at 6.5 mm displacement, while KJ04 (green) peaks at around 8 kN at 3 mm. KJ05 (purple) has the lowest peak load, about 6.8 kN at 2.5 mm displacement. All samples exhibit steep initial load increases, indicating high initial stiffness, with KJ01 and KJ02 being the stiffest. Post-peak,

Table 5. Basic material properties for different laminate configuration.

Specimen	Load value (kN)	Width (mm)	Thickness (mm)	Area (mm ²)	Compressive strength (MPa)
KJ01	12.514	100	3.63	363	34.47
KJ02	10.402	100	3.62	362	28.73
KJ03	9.336	100	3.6	360	25.93
KJ04	7.45	100	3.59	359	20.75
KJ05	6.014	100	3.65	365	16.48
KK01	10.489	100	3.65	365	28.74
KK02	9.762	100	3.67	367	26.60
KK03	14.302	100	3.68	368	38.86
KK04	12.218	100	3.64	364	33.57
KK05	14.52	100	3.65	365	39.78

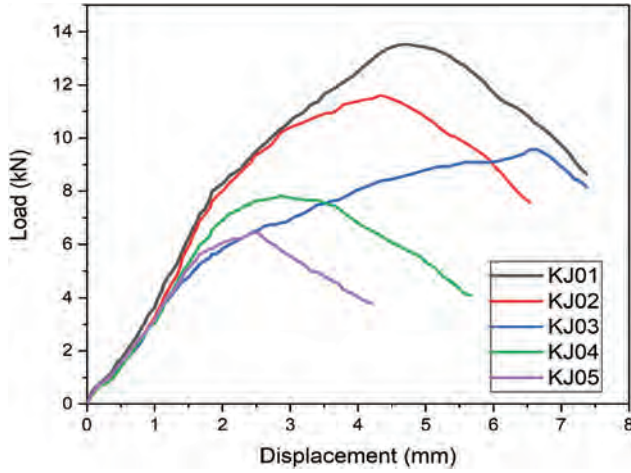


Figure 6. Load vs displacement for KJ laminate configuration.

all samples decline in load, with KJ01 and KJ02 showing sharper drops, indicating more brittle failure, whereas KJ03 shows a flatter post-peak curve, suggesting more ductility. Displacement at peak load varies, with KJ03 showing the highest, indicating greater ductility. Overall, KJ01 and KJ02 are the strongest, followed by KJ03, KJ04, and KJ05. Despite KJ03's lower peak load, it sustains load over a larger displacement, suggesting it is more ductile. KJ05 is the weakest in both peak load and displacement at failure. This analysis highlights the strength and ductility differences, informing material selection based on performance requirements.

Figure 7 illustrates the load–displacement relationship for five different samples (KJ01 to KJ05). KJ01 (black) reaches the highest peak load of approximately 14 kN at around 5 mm displacement, followed by KJ02 (red) with a peak load of about 12 kN at 4.5 mm. KJ03 (blue) shows a peak load of approximately 9 kN at 7 mm displacement, while KJ04 (green) peaks at around 8 kN at 4 mm. KJ05 (purple) has the lowest peak load, about 6 kN at 3 mm displacement. All samples exhibit steep initial load increases, indicating high initial stiffness, with KJ01 and KJ02 being the stiffest. Post-peak, all samples decline in load, with KJ01 and KJ02 showing sharper drops, indicating more brittle failure, whereas KJ03 shows a flatter post-peak curve, suggesting more ductility. Displacement at peak load varies, with KJ03 showing the highest, indicating greater ductility. Overall, KJ01 and KJ02 are the strongest, followed by KJ03, KJ04, and KJ05. Despite KJ03's lower peak load, it sustains load over a larger displacement, suggesting

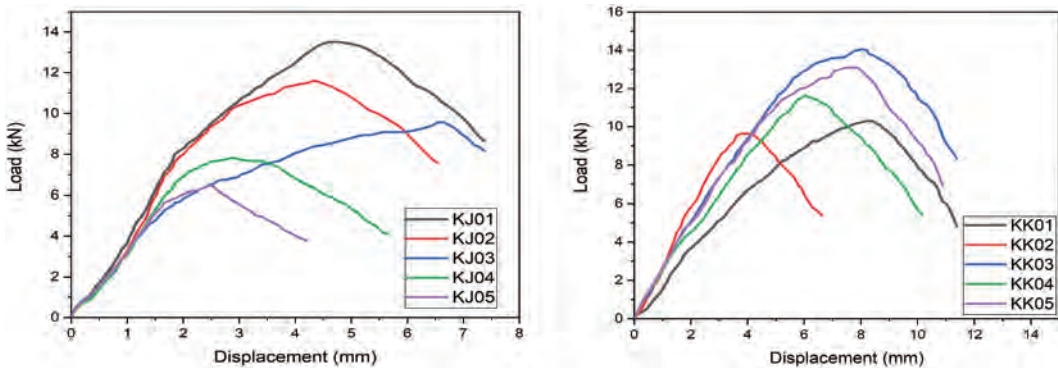


Figure 7. Load vs displacement for KJ (left) and KK (right) laminate configuration.

it is more ductile. KJ05 is the weakest in both peak load and displacement at failure. This analysis highlights the strength and ductility differences, informing material selection based on performance requirements.

For five samples (KK01 to KK05). KK03 (blue) reaches the highest peak load of approximately 15 kN at around 8 mm displacement, indicating the highest strength among the samples. KK05 (purple) follows closely with a peak load of about 14 kN at 9 mm, showing significant strength and ductility. KK02 (red) and KK04 (green) reach similar peak loads around 11 kN, but KK02 does so at about 5 mm displacement, while KK04 peaks at 6 mm, suggesting that KK02 has a slightly higher initial stiffness. KK01 (black) has the lowest peak load, approximately 10 kN at 5 mm displacement. Post-peak behavior varies, with KK02 showing a sharper decline indicating more brittle failure, while KK03 and KK05 have more gradual declines, suggesting better ductility. KK01 and KK04 exhibit intermediate behavior. This analysis highlights the varying strengths and ductility among the samples, with KK03 and KK05 showing the best combination of high load-bearing capacity and ductility, while KK02, despite its higher initial stiffness, displays more brittle behavior.

Figure 8 presents the load values and cross-sectional areas for Kevlar-Jute (KJ) and Kevlar-Kevlar (KK) composite specimens, each designed to evaluate the effect of drilled holes on residual strength. For the KJ specimens, KJ01 sustains the highest load at 12.5kN with an area of 363 mm². Among the drilled KJ specimens, load values progressively decrease as hole diameter and effective length increase. KJ02 and KJ03, which have smaller 4-mm holes, bear load values of 10.4 kN and 9.3kN, respectively, while maintaining similar cross-sectional areas of 362 mm² and 360 mm². This trend becomes more pronounced in KJ04 and KJ05, which feature larger 12-mm holes and exhibit further reductions in load capacity, with values of 7.45 kN and 6.0 kN, respectively. These results indicate that larger holes significantly weaken the load-bearing capacity of the KJ specimens. For the KK specimens (KK01), holds a load of 10.4kN with an area of 365 mm². Among the drilled KK specimens, KK02 and KK03, with 4 mm holes, support loads of 9.7 kN and 14.3 kN, respectively, across nearly identical areas, suggesting that factors such as effective length may impact KK specimens differently. KK04 and KK05, which have larger 12-mm diameter holes, maintain relatively high load values of 12.2kN and 14.5kN, despite the increased hole size. Interestingly, the larger holes in KK specimens do not result in as significant a reduction in load capacity as observed in KJ specimens, indicating that the all-Kevlar composition may offer better resilience to the stress concentrations caused by drilled holes. In summary, drilled holes impact the load-bearing capacity of KJ and KK specimens differently. KJ specimens demonstrate a marked decrease in load capacity with increased hole diameter, whereas KK specimens show greater resilience, which is evident due to higher strength of all – Kevlar configuration as compared to hybrid Kevlar-Jute configuration. These data highlight the differential effects of drilled holes on the structural integrity of hybrid versus all-Kevlar composites.

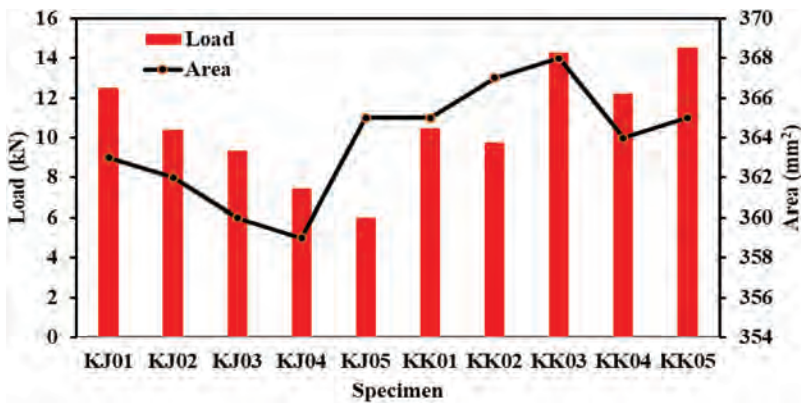


Figure 8. Maximum load taken by the specimen (load vs area).

Residual strength of the drilled specimens

$$\text{Residual strength}(\%) = \frac{\text{Strength}(\text{undrilled specimen} - \text{drilled specimen})}{\text{Strength of the undrilled specimen}} \times 100. \quad (2)$$

The formula calculates the percentage reduction in strength of a specimen due to the presence of a drilled hole. It measures how much the strength of the material has decreased due to the drilling, compared to an undamaged (undrilled) specimen. Table 6 presents the residual compressive strength and the corresponding percentage change in residual strength for Kevlar-Jute and Kevlar-Kevlar composite laminate samples under drilled hole conditions. It is important to note that positive values in the table represent a reduction in residual strength, while negative values indicate an increase in strength relative to the undrilled condition.

For the Kevlar-Jute specimen, the residual compressive strength consistently shows positive values, indicating a reduction in strength due to the drilled holes. For instance, KJ02 has a residual compressive strength of 5.73 MPa, corresponding to a 19.97% reduction. Similarly, KJ03 and KJ04 exhibit higher reductions of 32.93% and 66.12%, with residual compressive strengths of 8.54 MPa and 13.72 MPa, respectively. The largest reduction is observed in KJ05, where the residual compressive strength is 17.99 MPa, corresponding to a 109.23% decrease. This trend highlights that Kevlar-Jute composites experience significant strength losses after drilling, but the material retains measurable residual compressive strength values despite the reduction.

In contrast, the Kevlar-Kevlar samples exhibit negative percentage changes, indicating an increase in residual strength relative to the undrilled condition as shown in Figure 9. KK02 shows a minor strength increase of 7.43%, with a compressive strength of 2.13 MPa. More significant strength improvements are observed in KK03, KK04, and KK05, where the residual compressive strengths are -10.12 MPa, -4.82 MPa, and -11.04 MPa, corresponding to percentage changes of -35.24%,

Table 6. Residual strength and residual compressive strength for different laminate configuration.

Specimen	Residual strength change (%)	Residual compressive strength (MPa)
KJ02	20.0	5.7
KJ03	32.9	8.5
KJ04	66.1	13.7
KJ05	109.2	18.0
KK02	8.0	2.1
KK03	-26.1	-10.1
KK04	-14.4	-4.8
KK05	-27.8	-11.0

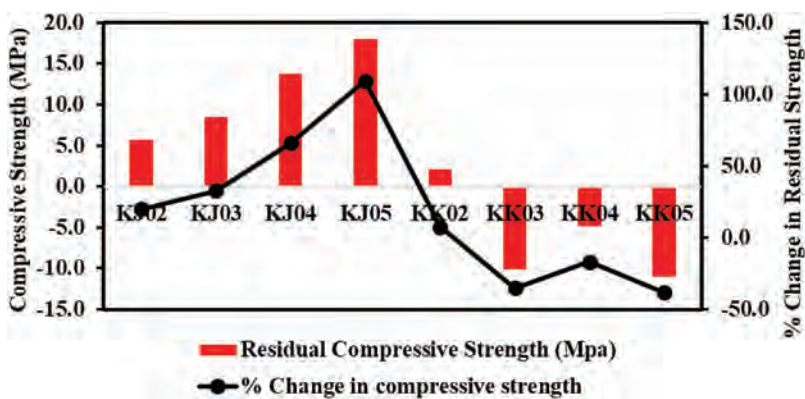


Figure 9. The percentage reduction in residual strength vs residual compressive strength.

–16.80%, and –38.43%, respectively. This suggests that Kevlar-Kevlar composites respond differently to drilling, possibly experiencing stress redistribution or localized stiffening around the drilled holes, which enhances compressive strength.

In summary, Kevlar-Jute composites exhibit a consistent reduction in strength under drilled conditions, while Kevlar-Kevlar composites show notable strength improvements. These contrasting behaviors highlight Kevlar-Kevlar's unique ability to resist or recover from drilling-induced damage, whereas Kevlar-Jute is more susceptible to degradation.

Effect of holes on residual strength

Residual strength indicates the remaining strength of the laminate after it has been subjected to drilling holes. Higher values suggest better retention of strength post-modification.

KJ02 (19.97), KJ03 (24.77): These specimens have moderate residual strength, suggesting that the combination of Kevlar and Jute fibers provides a decent level of durability after drilling.

KJ04 (39.8), KJ05 (52.2): These specimens show relatively high residual strength, indicating that the specific configuration or treatment of these samples made them more resilient to the weakening effects of drilling.

KK01 (7.43), KK04 (3.63): These specimens have very low residual strength, suggesting that the Kevlar-Kevlar configuration in these cases was less effective in retaining strength after drilling. This might be due to factors like hole placement, size, or the drilling method.

KK02 (35.24), KK03 (16.8): These specimens show better residual strength than KK01 and KK04, but still generally lower than the KJ series, indicating variability in how the Kevlar-Kevlar laminates respond to drilling.

The KJ series generally shows higher residual strength compared to the KK series, which suggest that the combination of Kevlar and Jute fibers provides better resistance to damage from drilling. The variability within each group (e.g., KJ02 vs. KJ05) indicates that factors such as hole size, placement, or even manufacturing inconsistencies might significantly impact residual strength. The particularly low values for KK01 and KK04 suggest potential issues like improper drilling technique and poor fiber-matrix bonding. The data suggest that Kevlar-Jute (KJ) composites tend to have higher and more consistent residual strength compared to Kevlar-Kevlar (KK) composites after drilling. This might be due to the synergistic effect of combining synthetic and natural fibers, which could help in distributing stress more effectively around the drilled holes. Further analysis would be required to identify the exact reasons for the variability and to optimize the laminate design for better performance.

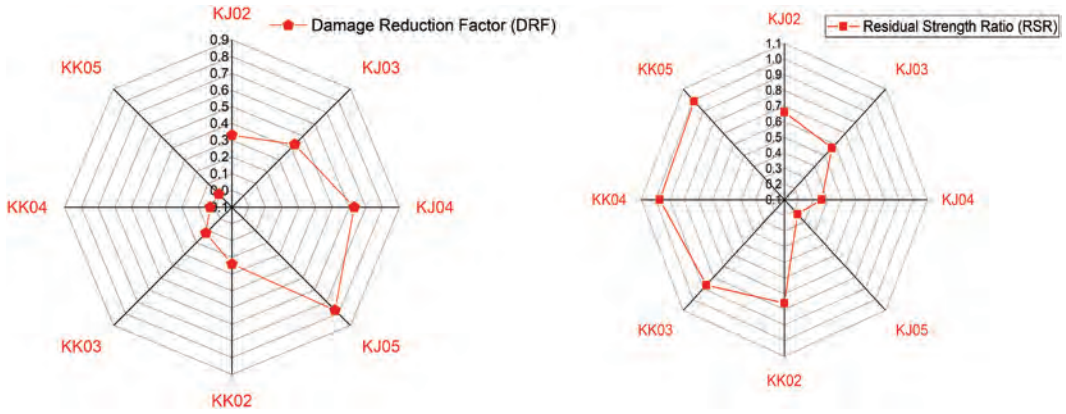
Damage reduction factor (DRF)

This parameter indicates the extent of strength reduction due to damage. DRF directly quantifies the reduction in compressive strength due to the presence of damage, such as drilling or other defects. This helps in understanding how much the strength has been compromised by the damage.

The Damage Reduction Factor (DRF) of the KJ05 hybrid composite laminate is higher than that of the KK laminate primarily due to differences in fiber strength and load distribution as shown in [Table 7](#). Kevlar, with its high tensile strength and impact resistance, significantly enhances the structural integrity of composite laminates. In the KK laminates, the series of Kevlar layers provides superior load-bearing capacity and effective stress distribution, reducing the extent of damage and maintaining higher residual strength, thus resulting in a lower DRF as shown in [Figure 10](#). In contrast, the KJ laminate, with Kevlar and Jute layers, faces reduced overall strength and stiffness. Jute fibers, being less strong and more prone to damage compared to Kevlar, lead to increased stress concentrations and more significant reductions in compressive strength when damaged. Consequently, the KJ configuration exhibits a higher DRF, indicating a greater reduction in strength due to its weaker Jute layers compared to the KK laminate's more resilient structure. The obtained conclusion is in line with studies represented in the literature (Saha et al. 2023).

Table 7. Damage reduction factor parameter for different laminate configurations.

Specimen	Compressive strength of the undamaged laminate (MPa)	Residual compressive strength after damage (MPa)	Damage Reduction Factor (DRF)
KJ02	34.4	22.9	0.33
KJ03	34.4	19.5	0.43
KJ04	34.4	12.4	0.63
KJ05	34.4	7.8	0.77
KK02	28.7	21.9	0.24
KK03	28.7	25.1	0.12
KK04	28.7	27.9	0.03
KK05	28.7	28.6	0.01

**Figure 10.** Damage reduction factor (DRF) and residual strength ratio (RSP) for different laminate configurations.

Residual load carrying capacity and effective stress post damage

The effective stress post-damage and residual load-carrying capacity of a KK composite laminate are higher compared to a KJ laminate due to the strategic placement of Kevlar layers as shown in Table 8. In the KK laminate, the Kevlar layers are positioned on the outer surfaces, where they can more effectively resist and distribute compressive loads and impacts, thus preserving strength and structural integrity. Kevlar's superior tensile strength and impact resistance contribute to better load-bearing performance and reduced damage propagation, leading to higher effective stress and residual load-carrying capacity after damage as shown in Figure 11. In contrast, the KJ laminate places Jute, which is less strong and more susceptible to damage, between the Kevlar layers. This arrangement results in higher stress concentrations and reduced overall load-carrying capacity because the inner Jute layers do not effectively support or distribute loads as well as Kevlar, leading to lower performance metrics post-damage. Thus,

Table 8. Residual load carrying capacity and effective stress post-damage for different laminate configurations.

Specimen	Residual Strength Ratio (RSR)	Residual Load-Carrying Capacity	Effective Stress Post-Damage (MPa)
KJ02	0.66	6.86	275.88
KJ03	0.57	5.32	259.54
KJ04	0.36	2.68	207.52
KJ05	0.23	1.38	164.78
KK02	0.76	7.42	237.27
KK03	0.87	12.44	186.09
KK04	0.97	11.84	239.08
KK05	0.99	14.37	276.92

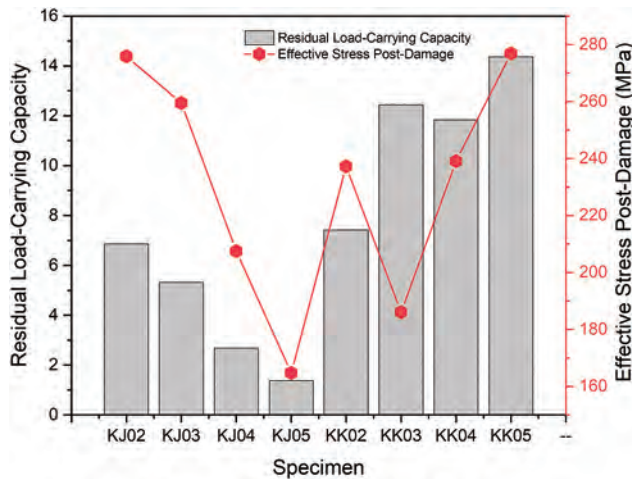


Figure 11. Residual load-carrying capacity vs effective stress post-damage.

the KK laminate benefits from enhanced damage resistance and load-bearing capability due to the optimal placement of Kevlar layers. The presence of holes in fiber-reinforced composites, such as Kevlar-based laminates, introduces notch sensitivity, which can lead to stress concentrations and potential failure. However, hybrid composites with a Kevlar core demonstrate lower notch sensitivity compared to single-fiber composites, due to progressive damage modes that delay failure (Khan et al. 2023).

Conclusion

Hybrid composites reinforced with Kevlar and Jute fibers are of low weight and also high stiffness and strength. The residual strength of these composite materials is also high under various sorts of loads. Hole generation became a better way of analysis of composites regarding their strengths and stiffness and mainly after damage effects. Kevlar-jute/epoxy composites are residually strong even after hole generation. Kevlar is a ballistic material when reinforced in bulk can withhold a greater extent of impact and when reinforced with natural fibers which are biodegradable as well as have higher resistivity toward torsional vibrations which occurs usually after damage or impact.

This study evaluated the residual compressive strength of Kevlar-Jute/Epoxy hybrid composite laminates with multiple drilled holes, providing insights into their structural resilience under compressive loads. Testing showed that the laminate configuration KK05 exhibited the highest residual compressive strength, retaining approximately 85% of its original strength after drilling, making it ideal for applications requiring high durability. Comparatively, other configurations retained between 65% and 75% of their initial compressive strength, indicating that stacking sequence plays a significant role in residual strength.

The damage reduction factor was lower for the KK05 configuration, suggesting minimal strength loss compared to others, while the residual strength ratio for KK05 remained consistently high. These results confirm that the KK05 configuration not only optimizes the balance between strength and weight but also demonstrates superior performance in sustaining load-bearing capacity post-damage, making it a promising option for protective gear, automotive components, and aerospace structures where impact resistance and sustainability are critical.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Author contributions

All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Data availability statement

All data generated or analyzed during this study are included in this article.

Highlights

- **Stacking Sequence Evaluation:** Compares the performance of two different stacking sequences of Kevlar and Jute reinforcements, providing insights into how composite layering impacts residual strength.
- **Impact of Hole Drilling:** Analyzes the residual properties of laminates with varying hole diameters (4 mm and 12 mm) and different effective lengths (2 mm and 4 mm) from the center hole, helping optimize drilling patterns for structural integrity.
- **Civil, Aerospace and Automotive Application:** Demonstrates that KK05 laminate configuration has superior residual compressive strength, making it suitable for high-performance applications in protective gear, aerospace structures, and automotive components.
- **Sustainability Focus:** Highlights the eco-friendly nature of Kevlar-Jute composites, promoting sustainable manufacturing practices without compromising on impact resistance or performance.
- **Practical Utility:** Provides essential data on damage reduction factors, residual load-carrying capacity, and effective stress post-damage, aiding the development of robust, lightweight composite materials for demanding industries.

References

- Adin, H., and M. Ş. Adin. 2022. "Effect of Particles on Tensile and Bending Properties of Jute Epoxy Composites." *Materials Testing* 64 (3): 401–411. <https://doi.org/10.1515/mt-2021-2038>.
- Aruchamy, K., S. K. Palaniappan, R. Lakshminarasimhan, B. Mysamy, S. K. Dharmalingam, N. S. Ross, and S. Pavayee Subramani. 2023. "An Experimental Study on Drilling Behavior of Silane-Treated Cotton/Bamboo Woven Hybrid Fiber Reinforced Epoxy Polymer Composites." *Polymers* 15 (14): 3075. <https://doi.org/10.3390/polym15143075>.
- Ashraf, M. A., M. Zwawi, M. Taqi Mehran, R. Kanthasamy, and A. Bahadar. 2019. "Jute Based Bio and Hybrid Composites and Their Applications." *Fibers* 7 (9): 77. <https://doi.org/10.3390/fib7090077>.
- Bhatia, G. S., and A. Arockiarajan. 2023. "Effect of Interactions of Two Holes on Tensile Behavior of Patch Repaired Carbon/Epoxy Woven Laminates." *Defence Technology* 21:88–93. <https://doi.org/10.1016/j.dt.2022.07.008>.
- Biruk-Urban, K., P. Bere, R. Udroui, J. Józwik, and K. Beer-Lech. 2024. "Understanding the Effect of Drilling Parameters on Hole Quality of Fiber-Reinforced Polymer Structures." *Polymers* 16 (16): Article 16. <https://doi.org/10.3390/polym16162370>.
- Bisaria, H., M. K. Gupta, P. A. Shandilya, and R. K. Srivastava. 2015. "Effect of Fibre Length on Mechanical Properties of Randomly Oriented Short Jute Fibre Reinforced Epoxy Composite." *Materials Today: Proceedings* 2 (4–5): 1193–1199. <https://doi.org/10.1016/j.matpr.2015.07.031>.
- Borah, P., and S. Samanta. 2022. "Wear Behaviour of Glass/Jute Hybrid Epoxy Composites with Addition of Fillers." *Advances in Materials and Processing Technologies* 8 (1): 54–67. <https://doi.org/10.1080/2374068X.2020.1793270>.
- Doan, T. T. L., H. Brodowsky, and E. Mäder. 2012. "Jute Fibre/Epoxy Composites: Surface Properties and Interfacial Adhesion." *Composites Science and Technology* 72 (10): 1160–1166. <https://doi.org/10.1016/j.compscitech.2012.03.025>.
- Du, Y., T. Yang, and C. Liu. 2023. "Investigation of Tensile Property and Strain Distribution of Drilled Carbon Fiber Reinforced Polyetheretherketone Composites." *Journal of Composite Materials* 57 (12): 1999–2012. <https://doi.org/10.1177/00219983231167572>.

- Elfaleh, I., F. Abbassi, M. Habibi, F. Ahmad, M. Guedri, M. Nasri, and C. Garnier. 2023. "A Comprehensive Review of Natural Fibers and Their Composites: An Eco-Friendly Alternative to Conventional Materials." *Results in Engineering* 19:101271. <https://doi.org/10.1016/j.rineng.2023.101271>.
- Fatima, S., and A. R. Mohanty. 2011. "Acoustical and Fire-Retardant Properties of Jute Composite Materials." *Applied Acoustics* 72 (2–3): 108–114. <https://doi.org/10.1016/j.apacoust.2010.10.005>.
- Goud, B. N., S. Sura, P. Aravind, B. J. Lal, K. Sanskruti, and C. Pavan. 2022. "An Experimental Study on Mechanical Properties of Kevlar Composite for Aircraft Structural Applications." *Materials Today: Proceedings*, 909–916, 64. <https://doi.org/10.1016/j.matpr.2022.06.053>.
- Hafez, R. D. A., A. Shubbar, M. S. Nasr, and R. O. A. A. Ftah. 2024. "Reinforcing the Brittle Resistance of High-Strength Concrete Using Agricultural Waste Fiber." *Sustainable Structures* 4 (3): 000058. <https://doi.org/10.54113/j.sust.2024.000058>.
- Hosseini, M., M. Gaff, H. Li, P. Konvalinka, J. Lair, D. Hui, P. Ghosh, et al. 2023. "A Review of the Performance of Fibre-Reinforced Composite Laminates with Carbon Nanotubes." *Nanotechnology Reviews* 12 (1): 20230164. <https://doi.org/10.1515/ntrev-2023-0164>.
- Hu, B., X. Chen, F. Deng, and X. Sun. 2023. "Evaluation of Failure Criteria for Residual Tensile Strength of Composite Laminates with Circular Holes." *Vibroengineering Procedia* 49:212–219. <https://doi.org/10.21595/vp.2023.23348>.
- Huang, Z., K. Zheng, Y. Wei, L. Liu, X. Tang, and Q. Xiaochuan. 2023. "Compressive Performance of SWSSC-Filled CFRP-Stainless Steel Composite Tube Columns." *Construction and Building Materials* 385:131471. <https://doi.org/10.1016/j.conbuildmat.2023.131471>.
- Jagadeesh, P., S. M. Rangappa, I. Suyambulingam, S. Siengchin, M. Puttegowda, J. S. Binoj, S. Gorbatyuk, et al. 2023. "Drilling Characteristics and Properties Analysis of Fiber Reinforced Polymer Composites: A Comprehensive Review." *Heliyon* 9 (3): e14428. <https://doi.org/10.1016/j.heliyon.2023.e14428>.
- Jin, F. L., X. Li, and S. J. Park. 2015. "Synthesis and Application of Epoxy Resins: A Review." *Journal of Industrial and Engineering Chemistry* 29:1–11. <https://doi.org/10.1016/j.jiec.2015.03.026>.
- Karthik, A., and P. S. Sampath. 2020. "Analysis of Thrust Force in Drilling Cotton with Bamboo Blended Fibre-Reinforced Composites Using Box-Behnken Methodology." *Indian Journal of Fibre & Textile Research* 45 (3): 267–273. <http://nopr.niscares.in/handle/123456789/55280>.
- Kenney, A., C. Zhang, L. Bhandari, R. Liang, and H. G. Rao. 2024. "Mechanical Response of Glass/Kevlar Hybrid Composite Jackets for Steel Containers Carrying Hazardous Materials to Enhance Safety." *Sustainable Structures* 4 (3): 000055. <https://doi.org/10.54113/j.sust.2024.000055>.
- Khan, M. K. A., H. Junaedi, H. Alshahrani, A. Wagih, G. Lubineau, and T. A. Sebaey. 2023. "Enhanced Open-Hole Strength and Toughness of Sandwich Carbon-Kevlar Woven Composite Laminates." *Polymers* 15 (10): Article 10. <https://doi.org/10.3390/polym15102276>.
- Kocaman, S., and G. Ahmetli. 2016. "A Study of Coating Properties of Biobased Modified Epoxy Resin with Different Hardeners." *Progress in Organic Coatings* 97:53–64. <https://doi.org/10.1016/j.porgcoat.2016.03.025>.
- Kumar, J., V. Kumar, I. Singh, and P. K. Rakesh. 2021. "Joining Behavior of Polymeric Composites Fabricated Using Agricultural Waste as Fillers." *Journal of Adhesion Science and Technology* 35 (15): 1652–1663. <https://doi.org/10.1080/01694243.2020.1855909>.
- Kumar, J., Y. Singh, P. K. Rakesh, I. Singh, and J. P. Davim. 2023. "The Impact of Hole Diameter on the Molded and Drilled Holes in Jute-Fiber-Reinforced Epoxy Composites." *Journal of Composites Science* 7 (9): Article 9. <https://doi.org/10.3390/jcs7090376>.
- Kumar, S., S. R. Chauhan, P. K. Rakesh, I. Singh, and J. P. Davim. 2012. "Drilling of Glass Fiber/Vinyl Ester Composites with Fillers." *Materials & Manufacturing Processes* 27 (3): 314–319. <https://doi.org/10.1080/10426914.2011.585489>.
- Li, H., Y. Wei, K. Meng, L. Zhao, B. Zhu, and B. Wei. 2024. "Mechanical Properties and Stress-Strain Relationship of Surface-Treated Bamboo Fiber Reinforced Lightweight Aggregate Concrete." *Construction and Building Materials* 424:135914. <https://doi.org/10.1016/j.conbuildmat.2024.135914>.
- Mahbub, R. F., L. Wang, L. Arnold, S. Kaneslingam, and R. Padhye. 2014. "Thermal Comfort Properties of Kevlar and Kevlar/Wool Fabrics." *Textile Research Journal* 84 (19): 2094–2102. <https://doi.org/10.1177/0040517514532157>.
- McAllister, Q. P., J. W. Gillespie, and M. R. VanLandingham. 2012. "Evaluation of the Three-Dimensional Properties of Kevlar Across Length Scales." *Journal of Materials Research* 27 (14): 1824–1837. <https://doi.org/10.1557/jmr.2012.80>.
- Mir, A., R. Zitoune, F. Collombet, and B. Bezzazi. 2010. "Study of Mechanical and Thermomechanical Properties of Jute/Epoxy Composite Laminate." *Journal of Reinforced Plastics & Composites* 29 (11): 1669–1680. <https://doi.org/10.1177/0731684409341672>.
- Nath, S., H. Jena, Priyanka, and D. Sahini. 2019. "Analysis of Mechanical Properties of Jute Epoxy Composite with Chemosphere Filler." *Silicon* 11 (2): 659–671. <https://doi.org/10.1007/s12633-018-9941-x>.
- Novák, I., J. Šimoníková, and I. Chodák. 2001. "Adhesive Properties of Epoxy Resin with Chromic Hardener." *Macromolecular Materials and Engineering* 286 (3): 191–195. [https://doi.org/10.1002/1439-2054\(20010301\)286:3<191::AID-MAME191>3.0.CO;2-N](https://doi.org/10.1002/1439-2054(20010301)286:3<191::AID-MAME191>3.0.CO;2-N).
- Oliwa, R. 2020. "The Mechanical Properties of Kevlar Fabric/Epoxy Composites Containing Aluminosilicates Modified with Quaternary Ammonium and Phosphonium Salts." *Materials* 13 (17): 3726. <https://doi.org/10.3390/ma13173726>.

- Olonisakin, K., S. He, Y. Yang, H. Wang, R. Li, and W. Yang. 2022. "Influence of Stacking Sequence on Mechanical Properties and Moisture Absorption of Epoxy-Based Woven Flax and Basalt Fabric Hybrid Composites." *Sustainable Structures* 2 (2): 000016. <https://doi.org/10.54113/j.sust.2022.000016>.
- Özdemir, B., A. Yardimeden, E. Bahce, E. Kilickap, and E. Emir. 2022. "Analysis of Drilling Behaviour in Jute Fibres Reinforced Natural Composites." *Journal of Natural Fibers* 20 (1). <https://doi.org/10.1080/15440478.2022.2159608>.
- Ozgul, E. O., and M. H. Ozkul. 2018. "Effects of Epoxy, Hardener, and Diluent Types on the Workability of Epoxy Mixtures." *Construction and Building Materials* 158:369–377. <https://doi.org/10.1016/j.conbuildmat.2017.10.008>.
- Park, S. J., M. K. Seo, T. J. Ma, and D. R. Lee. 2002. "Effect of Chemical Treatment of Kevlar Fibers on Mechanical Interfacial Properties of Composites." *Journal of Colloid and Interface Science* 252 (1): 249–255. <https://doi.org/10.1006/jcis.2002.8479>.
- Rana, R. S., J. Kumar, I. Singh, and A. K. Sharma. 2024. "Comparative Analysis of Drilled and Molded Holes in Short Natural Fiber Reinforced Composites." *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications* 238 (3): 493–503. <https://doi.org/10.1177/14644207231191618>.
- Reddy, P. V., R. V. S. Reddy, P. Rajendra Prasad, D. Mohana Krishnudu, R. M. Reddy, and H. R. Rao. 2020. "Evaluation of Mechanical and Wear Performances of Natural Fiber Reinforced Epoxy Composites." *Journal of Natural Fibers* 19 (6): 2218–2231. <https://doi.org/10.1080/15440478.2020.1807441>.
- Saba, N., M. T. Paridah, and M. Jawaid. 2015. "Mechanical Properties of Kenaf Fibre Reinforced Polymer Composite: A Review." *Construction and Building Materials* 76:87–96. <https://doi.org/10.1016/j.conbuildmat.2014.11.043>.
- Saha, P., M. F. Hossain, M. S. Rana, and M. S. Ferdous. 2023. "Numerical Modeling of Kevlar/Jute Fiber and Hybrid Composite Pressure Vessels." *Carbon Trends* 13:100304. <https://doi.org/10.1016/j.cartre.2023.100304>.
- Sangamesh, R., K. S. Ravishankar, and S. M. Kulkarni. 2020. "Performance Study of Jute-Epoxy Composites/Sandwiches Under Normal Ballistic Impact." *Defence Technology* 16 (4): 947–955. <https://doi.org/10.1016/j.dt.2019.11.011>.
- Sanjay, M. R., G. R. Arpitha, and B. Yogesha. 2015. "Study on Mechanical Properties of Natural-Glass Fibre Reinforced Polymer Hybrid Composites: A Review." *Materials Today: Proceedings* 2 (4–5): 2959–2967. <https://doi.org/10.1016/j.matpr.2015.07.264>.
- Sarwar, A., Z. Mahboob, R. Zdero, and H. Bougherara. 2020. "Mechanical Characterization of a New Kevlar/Flax/Epoxy Hybrid Composite in a Sandwich Structure." *Polymer Testing* 90:106680. <https://doi.org/10.1016/j.polymertesting.2020.106680>.
- Singh, S. P., A. Dutt, and C. K. Hirwani. 2022. "Mechanical, Modal and Harmonic Behavior Analysis of Jute and Hemp Fiber Reinforced Polymer Composite." *Journal of Natural Fibers* 20 (1). <https://doi.org/10.1080/15440478.2022.2140328>.
- Singh, T. J., and S. Samanta. 2015. "Characterization of Kevlar Fiber and Its Composites: A Review." *Materials Today: Proceedings* 2 (4–5): 1381–1387. <https://doi.org/10.1016/j.matpr.2015.07.057>.
- Strzelec, K., E. Leśniak, and G. Janowska. 2005. "New Polythiourethane Hardeners for Epoxy Resins." *Polymer International* 54 (9): 1337–1344. <https://doi.org/10.1002/pi.1861>.
- Suhad, D. S. 2020. "Effects of Jute Fibre Content on the Mechanical and Dynamic Mechanical Properties of the Composites in Structural Applications." *Defence Technology* 16 (6): 1098–1105. <https://doi.org/10.1016/j.dt.2019.11.013>.
- Thomason, J. L., L. Yang, and R. Meier. 2014. "The Properties of Glass Fibres After Conditioning at Composite Recycling Temperatures." *Composites Part A, Applied Science and Manufacturing* 61:201–208. <https://doi.org/10.1016/j.compositesa.2014.03.001>.
- Tripathy, S. S., L. Di Landro, D. Fontanelli, A. Marchetti, and G. Levita. 2000. "Mechanical Properties of Jute Fibers and Interface Strength with an Epoxy Resin." *Journal of Applied Polymer Science* 75 (13): 1585–1596. [https://doi.org/10.1002/\(SICI\)1097-4628\(20000328\)75:13<1585::AID-APP4>3.0.CO;2-Q](https://doi.org/10.1002/(SICI)1097-4628(20000328)75:13<1585::AID-APP4>3.0.CO;2-Q).
- Varga, C., N. Miskolczi, L. Bartha, and G. Lipóczy. 2010. "Improving the Mechanical Properties of Glass-Fibre-Reinforced Polyester Composites by Modification of Fibre Surface." *Materials & Design* 31 (1): 185–193. <https://doi.org/10.1016/j.matdes.2009.06.034>.
- Wang, H., H. Memon, A. M. Hassan, E. Miah, and M. A. Ali. 2019. "Effect of Jute Fiber Modification on Mechanical Properties of Jute Fiber composite." *Materials*. *Materials* 12 (8): 1226. <https://doi.org/10.3390/ma12081226>.
- Wei, Y., X. Zhang, G. Wu, and Y. Zhou. 2018. "Behaviour of Concrete Confined by Both Steel Spirals and Fiber-Reinforced Polymer Under Axial Load." *Composite Structures* 192 (5): 577–591. <https://doi.org/10.1016/j.compstruct.2018.03.041>.
- Yeung, K. H., and K. P. Rao. 2012. "Mechanical Properties of Kevlar-49 Fibre Reinforced Thermoplastic Composites." *Polymers & Polymer Composites* 20 (5): 411–424. <https://doi.org/10.1177/096739111202000501>.
- Zarif Karimi, N., H. Heidary, G. Minak, and M. Ahmadi. 2013. "Effect of the Drilling Process on the Compression Behavior of Glass/Epoxy Laminates." *Composite Structures* 98:59–68. <https://doi.org/10.1016/j.compstruct.2012.10.044>.