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Fabrication and Characterization of Kenaf and Kevlar Fibre Reinforced Graphene Filled Hybrid Composite Laminates for Engineering Applications

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Abstract

The present study investigates the mechanical properties of hybrid polymer composites reinforced with Kenaf and Kevlar-29 fibres, enhanced with graphene powder as a dopant. The novelty of this research lies in the synergistic combination of natural and synthetic fibres with graphene to optimize strength and hardness, providing a sustainable yet high-performance composite solution. Laminated plates were fabricated using a hand layup technique with graphene loadings ranging from 0.5 wt.% to 1.5 wt.%, and three distinct stacking configurations were explored: (1) Kenaf as outer layers with Kevlar-29 in between, (2) Kevlar-29 as outer layers with Kenaf in between, and (3) alternating Kenaf and Kevlar-29 layers. Flexural and hardness tests revealed that graphene loadings of 0.5 wt.% and 1.5 wt.% significantly improved flexural strength, particularly in Kenaf-Kevlar hybrid configurations. However, lower graphene concentrations (0.5 wt.%–1 wt.%) led to reduced hardness. The optimal performance was observed at 1 wt.%–1.5 wt.% graphene, attributed to its uniform dispersion and strong interfacial adhesion. These findings highlight the effectiveness of graphene in enhancing the mechanical properties of Kenaf- and Kevlar-reinforced composites while emphasizing the importance of mitigating nanoparticle aggregation. This work provides a novel approach to balancing sustainability with high-performance reinforcement in polymer composites.

Major Findings: *The Graphene filler at 1 wt.%–1.5 wt.% significantly enhances flexural strength and hardness in Kenaf-Kevlar composites. However, lower graphene loadings (0.5 wt.%–1 wt.%) reduce hardness. Optimal performance is achieved through uniform dispersion and strong interfacial adhesion while avoiding graphene aggregation in the Keanf-Kevlar Hybrid Composites.*

Keywords: *Flexural, Graphene, Hand Layup, Hardness, Kenaf Fibres, Kevlar Fibres, Mechanical Properties, Polymer Matrix Composites*

1.0 Introduction

Over the past two decades, considerable research has focused on the incorporation of natural fibres into Polymer Matrix Composites (PMCs), garnering significant attention in both academia and industry[1,2]. Synthetic fibres like Kevlar[3], glass[4], and carbon[5], while widely used for reinforcing plastics, are costly and derived from non-renewable resources, prompting the exploration of sustainable alternatives.

Natural fibres, such as Kenaf, have proven to be promising substitutes for glass fibre-reinforced composites in industrial applications, including packaging, paper production, and structural materials[6]. Kenaf is a rapidly growing annual plant with an average yield of 1700 kg/ha, requiring minimal water for cultivation. Derived from the

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bast of Hibiscus cannabinus stems, Kenaf is renewable, lightweight, low-cost, non-toxic, and offers moderately high specific strength, making it an ideal reinforcing agent for polymeric resins. Its use in automotive components underscores its mechanical advantages and suitability for lightweight applications[7].

Kevlar, a synthetic para-aramid fibre developed by DuPont in 1971, is widely recognized for its exceptional strength-to-weight ratio, high modulus, and toughness. Its ability to resist high-speed impacts and absorb energy efficiently makes it ideal for structural and aerospace systems[8,9]. Kevlar's molecular structure, consisting of benzene rings and amide bonds, contributes to its suitability for high-performance applications, including ballistic materials[10].

Recent advancements in hybrid composites have integrated natural and synthetic fibres with nanomaterials like graphene to enhance mechanical, thermal, and electrical properties[11]. Graphene nanoplatelets have been shown to improve fracture toughness and damage tolerance through mechanisms such as crack deflection and bridging[12]. Additionally, graphene's high thermal and electrical conductivity imparts multifunctional characteristics to hybrid composites[13]. Tailoring the microstructure and optimizing composition are critical for maximizing the benefits of these advanced materials. Veena C *et al.*, have reviewed the effect of the optimization of the natural fibres on the properties of the hybrid composites and have reported that the natural fibres if reinforced in optimum wt.% can maximize the benefits of using natural fibre reinforced composites[14]. Similarly Praveena B A *et al.,* have reported the findings of hybrid natural fibre reinforced dammar gum-epoxy bio composites. The hybridization effect has profound impact on the performance of multifunctional composites, especially the mechanical characteristics[15]. Aswathanarayan M S *et al.*, have reported the influence of nano graphene on the properties of the composites. The nano graphene filler enhances the mechanical strength while improving the adhesion and toughening in the composites[16]. Similarly, Malyadri T *et al.*, have analyzed the impact of graphene filler material in enhancing the static and dynamic mechanical characteristics of the composites. It is reported that there is a drastic improvement in the properties of the hybrid composites owing to micro coring and segregation brought about by the graphene nano platelets[17]. Santhosh N *et al.*, have reviewed the effect of natural fibre reinforcements on the characteristics of the composites and reported that the natural fibres along with the synthetic ones in hybridized network enhances the strength and toughness of the composites[18]. From the thorough review of the literature, it is herewith noted that the graphene filler along with natural and synthetic fibres significantly enhances the characteritics of the composites, which forms the basis for the current research work.

This study investigates hybrid composites made of Kenaf and Kevlar-29 fibres reinforced with graphene and vinyl ester resin. The mechanical properties, including flexural strength and hardness, are evaluated to determine the potential of these materials for high-performance, multifunctional applications in areas such as wind turbine blades and aerospace components.

2.0 Materials and Methods

2.1 Materials

The composite plates evaluated in this study were fabricated using Kenaf fibre, Kevlar 29 mat fibre, vinyl ester resin, cobalt accelerator, MEKP catalyst, hardener and graphene powder. The Kenaf fibre (Go Green Products Ltd., Chennai, India) consisted of tightly woven Kenaf fibres in a plain mat pattern with an areal density of 600 g/m^2. The Kelvar 29 fibre (Go Green Products Ltd., Chennai, India) consisted of tightly woven Kenaf fibres in a plain mat pattern with an areal density of 300 g/m^2. The vinyl ester resin, cobalt accelerator, MEKP catalyst, hardener were procured from blackcarbon composites. The graphene powder had an average thickness of 5 nm-10 nm. The table 1, gives the properties of the Kenaf and Kevlar - 29 fibres as provided in the Supplier Data Sheet (Go Green Products Ltd., Chennai, India).

2.2 Fabrication

Composite laminates were fabricated using the hand layup method in nine configurations combining kenaf, kevlar, and graphene powder[19]. The first configuration used Kenaf fibres in the top and bottom layers with Kevlar in the middle, while the second reversed this arrangement[20]. The third configuration alternated layers of Kenaf and Kevlar. Similarly 9 different combinations were fabricated with different layers of Kenaf and Kevlar and graphene reinforcements in the matrix[21]. All laminates

Table 1. Property table of kenaf and kevlar - 29 fibre as provided in the supplier data sheet

Property	Kenaf fibre	Kevlar-29 fibre
Density (g/cm³)	1.2–1.5	1.44
Tensile Strength (MPa)	200–600	3000–3600
Young's Modulus (GPa)	11–60	60–112
Elongation at Break (%)	1.5–2.5	2.8–4.0
Water Absorption (%)	High (up to 10–12%)	Very Low (<1%)
Thermal Stability (°C)	Decomposes at ~220–250°C	Stable up to ~500°C

incorporated vinyl ester resin, cobalt accelerator, MEKP catalyst, hardener, and graphene nanopowder (0.5 wt.%–1.5 wt.%)[22]. The graphene was dispersed into the resin through mechanical stirring at 500 rpm for 30 minutes to ensure uniform distribution[23]. The final laminates measured 300 mm × 300 mm × 3 mm –3.5 mm.

2.3 Characterization

The mechanical and microstructural properties of the composites were characterized using standardized tests and microscopic analysis. Hardness was measured following ASTM D2240, which specifies the procedure for determining the indentation hardness of polymer composites, elastomers, and rubbers. This test provided valuable insights into the surface resistance of the materials[24].

Flexural properties were assessed using the three-point bending test as per ASTM D790-17. The test involved a support span of 48 mm and a crosshead speed of 5 mm/min. Flexural stiffness was calculated from the slope of the initial linear segment of the load-deflection curve, offering a measure of the composite's resistance to bending under load[25].

Tensile testing was performed according to ASTM D638, with specimens cut to standard dimensions. A tensile load was applied at a crosshead speed of 5 mm/min until failure, and the maximum tensile stress was computed from the failure load, providing an evaluation of the material's strength under tension[26].

The microstructure of the composites was analyzed using Scanning Electron Microscopy (SEM). Fracture surfaces from tensile tests were examined to understand the failure mechanisms. SEM was also employed to evaluate the dispersion of graphene nanoplatelets within the matrix, which is critical for ensuring uniformity and optimizing the mechanical performance of the composites.

3.0 Results and Discussions

3.1 Flexural Test Results

The Table 2 presents flexural testing results for composite samples comprising Kenaf (k1), Kevlar-29 (k2), and graphene (G). Different stacking sequences and graphene weight percentages viz., 0.5 wt.%, 1 wt.% and 1.5 wt.% (0.5G, 1G, 1.5G) were analyzed for their effects on flexural strength and load-bearing capacity. The width and thickness of the samples vary slightly, reflecting the influence of material composition and graphene addition.

Table 2. Flexural testing results for different combination of composites (k1= Kenaf k2=Kevlar-29 G= graphene)

Sample details	Width (mm)	Thickness (mm)	Load at peak (N)	Flexural Strength (MPa)
2k1+2k2+2k1+0.5G	13.02	5.42	173	84.9
2k1+2k2+2k1+1G	13.25	5.83	176	73.4
2k1+2k2+2k1+1.5G	13.01	5.43	211	102.87
2k2+2k1+2k2+0.5G	12.92	4.12	250	212.42
2k2+2k1+2k2+1G	12.98	4.72	215	138.75
2k2+2k1+2k2+1.5G	12.97	3.78	193	195.89
k1+k2+k1+k2+k1+k2+0.5G	12.98	4.88	253	153.23
k1+k2+k1+k2+k1+k2+1G	12.93	4.82	208	130.64
k1+k2+k1+k2+k1+k2+1.5G	12.87	4.08	250	163.33

The results indicate that graphene improves interfacial bonding and mechanical properties, with optimal performance depending on the stacking sequence and graphene content. Kevlar-rich configurations, such as 2k2+2k1+2k2, deliver superior flexural strength, peaking at 212.42 MPa with 0.5G. However, excessive graphene (1.5G) can cause agglomeration, reducing effectiveness. Alternating sequences (e.g., k1+k2 repeated) offer balanced performance but do not outperform Kevlar-dominant arrangements.

Thickness also impacts strength; thinner samples tend to exhibit higher flexural strength due to stress concentration[27,28]. Overall, the configuration 2k2+2k1+2k2 with 0.5G provides the best performance, emphasizing the importance of optimizing fibre arrangement and graphene content for tailored mechanical properties. The Figures 1, 2 and 3 gives the flexural stress strain diagram for the three configurations.

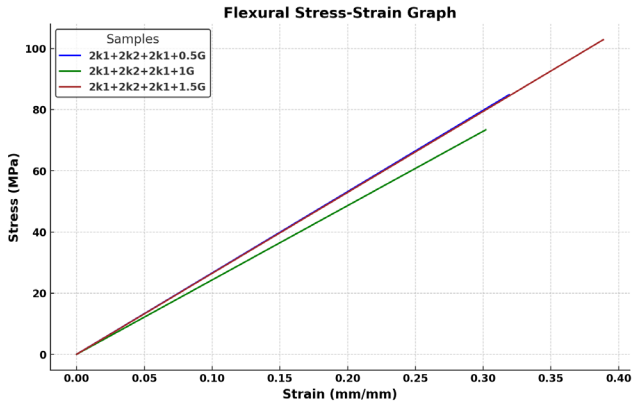


Figure 1. Flexural stress-strain graph for 2k1+2k2+2k1 configuration.

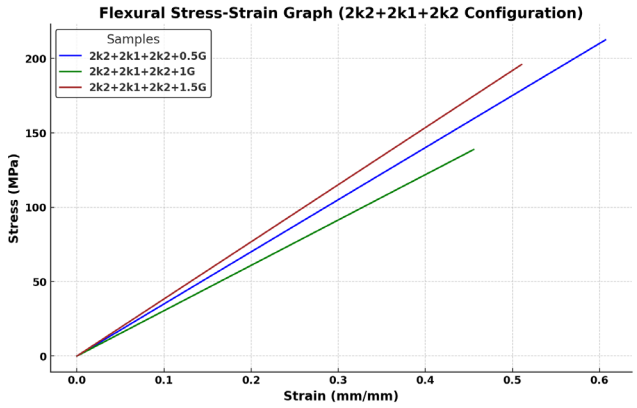


Figure 2. Flexural stress-strain graph for 2k2+2k1+2k2 configuration.

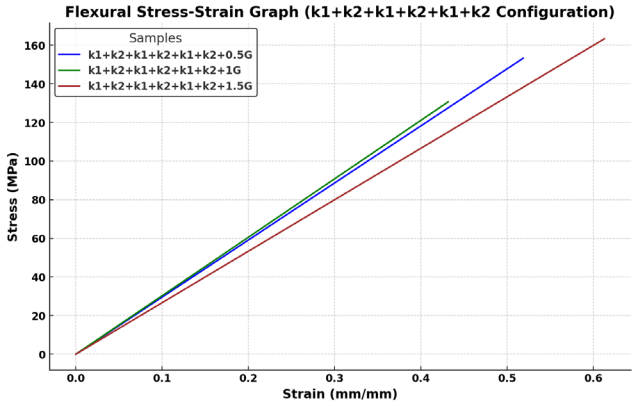


Figure 3. Flexural stress-Strain graph for k1+k2+k1+k2 +k1+k2 configuration.

3.2 Hardness Test Results

The table 3 summarizes the Vickers Hardness Number (VHN) results for various composite samples with different configurations and graphene content. VHN measures a material's resistance to indentation, providing insight into its mechanical durability. The samples feature three main fibre stacking sequences: Kenaf-dominant (2k1+2k2+2k1), Kevlar-dominant (2k2+2k1+2k2), and alternating layers of Kenaf and Kevlar (k1+k2+k1+k2+k1+k2). Each sequence is tested with three levels of graphene reinforcement (0.5G, 1G, and 1.5G).

The results indicate that increasing graphene content generally enhances hardness due to improved load transfer and bonding within the composite structure. For example, the Kenaf-dominant configuration (2k1+2k2+2k1) shows a gradual increase in VHN, from 78.6 (0.5G and

Table 3. Hardness test results

Sl.No	Sample details	VHN
1	2k1+2k2+2k1+0.5G	78.6
2	2k1+2k2+2k1+1G	77.5
3	2k1+2k2+2k1+1.5G	79.3
4	2k2+2k1+2k2+0.5G	73.3
5	2k2+2k1+2k2+1G	72.1
6	2k2+2k1+2k2+1.5G	74
7	k1+k2+k1+k2+k1+k2+0.5G	74.3
8	k1+k2+k1+k2+k1+k2+1G	70
9	k1+k2+k1+k2+k1+k2+1.5G	76.6

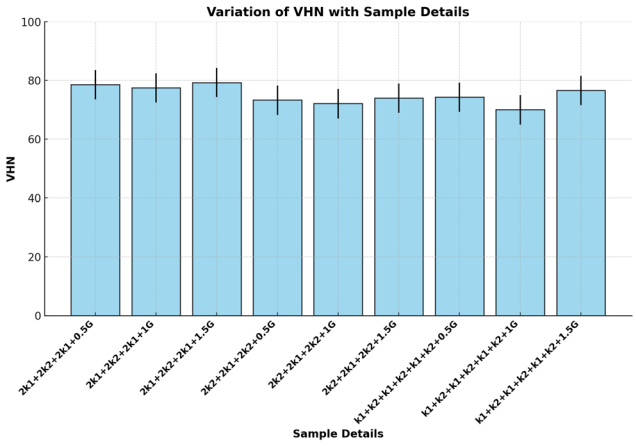


Figure 4. Hardness values for different specimen configurations.

1G) to 79.3 (1.5G). In contrast, the Kevlar-dominant configuration (2k2+2k1+2k2) has lower hardness values overall, ranging from 73.3 (0.5G and 1G) to 74.0 (1.5G). Alternating layers (k1+k2+k1+k2+k1+k2) exhibit the widest variation, with VHN values from 70.0 (1G) to 76.6 (1.5G). The figure 4 gives the graph of hardness variations for different composite configurations.

Overall, the Kenaf-dominant configuration demonstrates superior hardness compared to Kevlar-dominant or alternating arrangements, likely due to the higher stiffness and rigidity of Kenaf fibres[29]. The data also highlight the incremental but significant contribution of graphene reinforcement, with 1.5G achieving the highest hardness in most cases. These findings emphasize the need to optimize graphene content and stacking sequences to enhance hardness properties for specific applications. The Vickers Hardness test provides an adaptable and accurate method for hardness measurement across a wide range of materials, including composite specimens, with applications in quality control, research, and material development. The table 4 gives the hardness test results.

3.3 Tensile Test Results

The table 4 presents tensile strength and elongation data for composite samples with three stacking configurations—2k1+2k2+2k1, 2k2+2k1+2k2, and k1+k2+k1+k2+k1+k2—tested with varying graphene content (0.5G, 1G, 1.5G). These parameters evaluate the material's tensile resistance and ductility. Among the configurations, 2k2+2k1+2k2 exhibits the highest tensile strength (204.4 MPa) and elongation (7.26%) at

Table 4. Tensile test results

Sample details	Tensile Strength (MPa)	Elongation (%)
2k1+2k2+2k1+0.5G	28.235	1.8
2k1+2k2+2k1+1G	67.152	4.45
2k1+2k2+2k1+1.5G	46.179	2.21
2k2+2k1+2k2+0.5G	193.409	6.02
2k2+2k1+2k2+1G	204.4	7.26
2k2+2k1+2k2+1.5G	145.42	4.78
k1+k2+k1+k2+k1+k2+0.5G	118.77	5.59
k1+k2+k1+k2+k1+k2+1G	107.309	4.94
k1+k2+k1+k2+k1+k2+1.5G	150.04	6.1

1G graphene, attributed to Kevlar's inherent strength and improved fibre-matrix bonding. The alternating configuration (k1+k2+k1+k2+k1+k2) offers a balanced performance, peaking at 150.04 MPa tensile strength and 6.1% elongation at 1.5G graphene. The 2k1+2k2+2k1 configuration shows comparatively lower values, with its best performance (67.152 MPa and 4.45%) also at 1G graphene. Graphene content significantly influences the properties, with 1G proving optimal for all configurations, enhancing both strength and elongation. Excess graphene (1.5G) tends to reduce performance, likely due to agglomeration and poor stress distribution. These findings highlight the need for precise graphene optimization to achieve the desired mechanical properties. The Figures 5, 6 and 7 gives the tensile stress - strain diagram for all the three configurations.

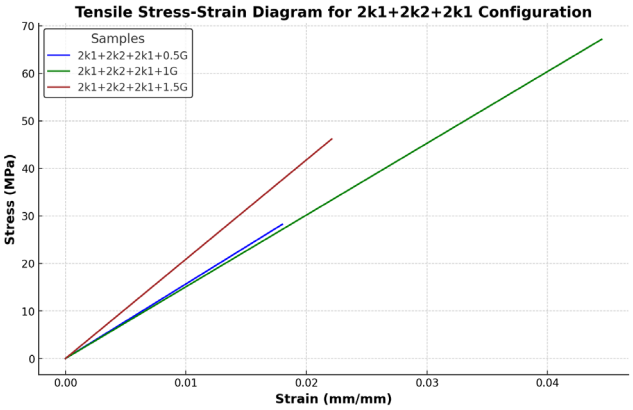


Figure 5. Tensile stress-strain graph for 2k1+2k2+2k1 configuration,

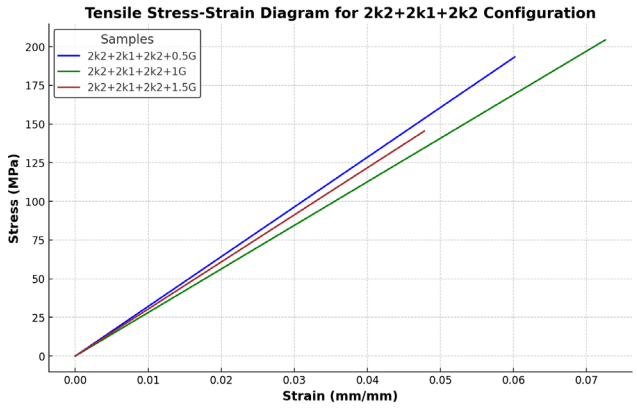


Figure 6. Tensile stress-strain graph for 2k2+2k1+2k2 configuration.

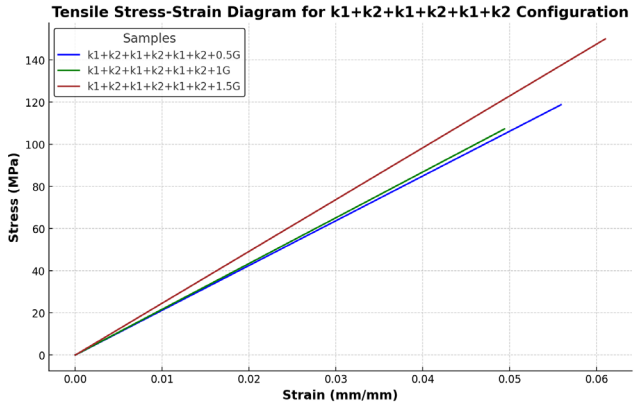


Figure 7. Tensile stress-strain graph for k1+k2+k1+k2+k1+k2 configuration.

3.4 Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) is an essential technique for evaluating the morphological effects of incorporating graphene nanoplatelets at increasing weight percentages into Kenaf and Kevlar fibres[30]. Unmodified Kenaf and Kevlar fibres typically display relatively smooth, clean surfaces in SEM imaging, with occasional defects, pores, and variations in fibre diameter attributed to their manufacturing processes. The smooth morphology of these fibres facilitates composite fabrication by providing an optimal interface for adhesion with the polymer matrix. The SEM images for 2k2+2k1+2k2 configuration which exhibits better flexural, tensile and hardness characteristics, viz., for the 0.5G, 1G and 1.5G provide a clear depiction of the fibre-matrix interactions and the influence of graphene nanoplatelets on the composite's structural properties. In Figure 8, i.e., the SE micrograph of

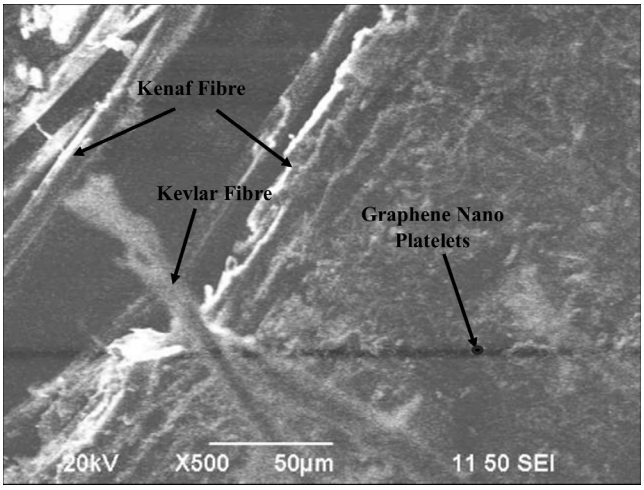


Figure 8. SEM image of 2k1+2k2+2k1+0.5G configuration.

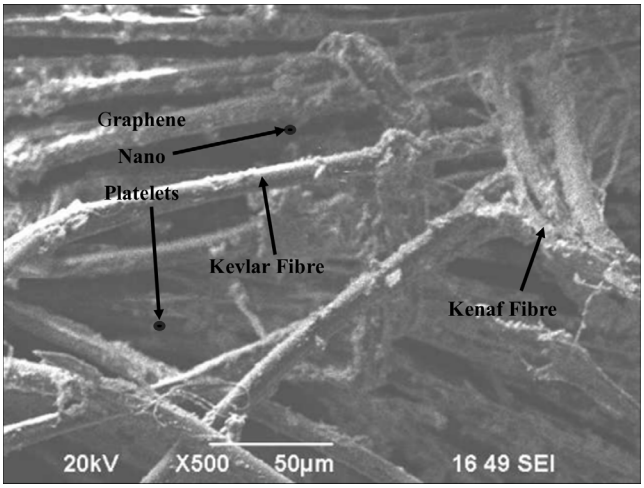


Figure 9. SEM image of 2k1+2k2+2k1+1G configuration.

2k2+2k1+2k2+0.5G specimen, the fibre-matrix bonding appears moderately effective, with a relatively smooth interface and minimal defects. This suggests a reasonable level of adhesion, allowing some degree of stress transfer between the fibres and the matrix. However, the bonding is not optimal, as slight irregularities and gaps indicate areas where the mechanical performance of the composite may be compromised under higher loads.

In contrast, Figure 9, i.e., the SE micrograph of 2k2+2k1+2k2+1G specimen reveals the presence of voids and imperfections at the fibre-matrix interface, which significantly reduce the composite's strength. These defects are indicative of weaker adhesion, possibly resulting from inconsistencies during the fabrication process or inadequate reinforcement within the matrix.

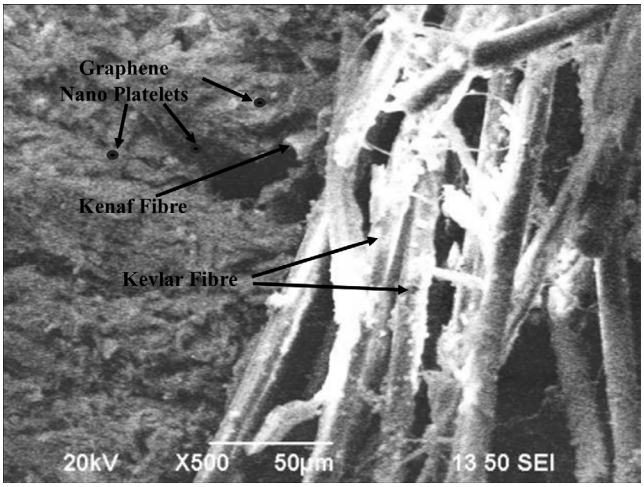


Figure 10. SEM image of 2k1+2k2+2k1+1.5G configuration.

The voids serve as stress concentration points, facilitating crack propagation and reducing the overall load-bearing capacity of the composite. This highlights the challenges of achieving uniform bonding and the detrimental effects of poor interfacial adhesion on mechanical properties.

Figure 10 (SE micrograph of 2k2+2k1+2k2+1.5G specimen) demonstrates a marked improvement in fibre strength and bonding, attributed to the inclusion of graphene nanoplatelets. The enhanced surface morphology, characterized by fewer defects and a more robust fibre-matrix interface, suggests that graphene nanoplatelets play a pivotal role in reinforcing the composite structure. The improved adhesion promotes efficient stress transfer from the matrix to the fibres, significantly enhancing the composite's mechanical performance. This highlights the effectiveness of graphene nanoplatelets in mitigating defects and optimizing the structural integrity of the material. Together, these observations underscore the critical importance of interfacial bonding and defect minimization in achieving superior composite properties.

In summary, the SEM analysis highlights the effects of graphene nanoplatelet reinforcement across the three configurations. The 2k1+2k2+2k1+0.5G configuration shows moderately effective fibre-matrix bonding with smooth surfaces and minimal defects. While the addition of 0.5G graphene nanoplatelets marginally improves adhesion, the enhancement in mechanical properties remains limited due to the persistence of minor imperfections.

The 2k1+2k2+2k1+1G configuration reveals the presence of voids and slight debonding at the fibre-matrix interface. Although graphene nanoplatelets contribute to reinforcement, the potential for agglomeration at this concentration introduces defects that hinder stress transfer and reduce mechanical strength compared to other configurations.

In contrast, the 2k1+2k2+2k1+1.5G configuration demonstrates the most robust performance, with enhanced bonding and reduced defects. The higher graphene nanoplatelet concentration ensures better interfacial adhesion, facilitating efficient stress transfer and significantly improving mechanical properties. This suggests 1.5G as the optimal reinforcement level for achieving superior composite strength and integrity.

4.0 Conclusions

The study evaluates the mechanical and morphological properties of hybrid polymer composites reinforced with Kenaf and Kevlar fibres and varying graphene nanoplatelet (G) concentrations. Key findings are as follows:

- 2k2+2k1+2k2 configuration (Kevlar-dominant) achieved the highest flexural strength of 212.42 MPa with 0.5 wt.% of graphene (0.5G).
- Excess graphene (1G) caused agglomeration, reducing flexural performance, while alternating Kenaf-Kevlar layers offered balanced strength.
- 2k1+2k2+2k1 configuration (Kenaf-dominant) demonstrated the highest hardness of 79.3 VHN with 1.5 wt.% of graphene.
- Kevlar-dominant configurations exhibited lower hardness values, while alternating layers showed variable results.
- 2k2+2k1+2k2 showed the highest tensile strength (204.4 MPa) and elongation (7.26%) at 1G graphene, attributed to Kevlar's inherent strength and good bonding.
- Alternating layers performed well with a balanced tensile strength of 150.04 MPa and elongation of 6.1% at 1.5wt.% of graphene.
- 0.5 wt.% of graphene moderately improved bonding but left minor imperfections, 1 wt.% of graphene introduced voids due to agglomeration, affecting interfacial adhesion, while 1.5 wt.% of graphene ensured the best bonding, with a smooth and defect-free interface.

- 0.5 wt.% and 1 wt.% of graphene offers an optimal balance of strength and hardness, while 1.5 wt.% of graphene enhances hardness and bonding.
- The Kevlar-dominant configuration is best for tensile and flexural strength, Kenaf-dominant for hardness, and alternating layers for balanced properties.

These findings highlight the importance of optimizing graphene content and fibre stacking sequences for applications in aerospace, automotive, and structural engineering. Further research is needed to address graphene dispersion challenges for improved composite performance.

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