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The Characterization and Development of Kenaf and Graphene Nanoplatelets in Polylactic Acid Composites

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ABSTRACT

Kenaf fiber is in high demand due to the need for lightweight composites, particularly in the automobile industry and occasionally for interior building materials. Its remarkable strength and low density are the main causes of this. The use of natural fiber as a bio-composite material is limited because it is less heat resistant compared to synthetic fiber. To bolster the mechanical robustness of kenaf composites, graphene nanoplatelets (GnP) are incorporated as a supplementary reinforcing agent. Numerous studies have explored the mechanical properties of composites made from natural fibers and polymer matrices, with the recent market introduction of polylactic acid (PLA) polymers as biodegradable matrix options for biocomposites. The objective of this study is to determine the effects of incorporating graphene fillers on the tensile and flexural properties of PLA, kenaf, GnP composites. Hot pressing compression moulding is employed to fabricate the composite samples consisting of varying compositions, ranging from 95% PLA, 5% kenaf, and 0% GnP to 80% PLA, 15% kenaf, and 5% GnP. The result shows that adding 5% Graphene Nanoplatelets as a reinforcing filler will enhance the tensile strength and tensile modulus up to 18.2% and 53.2% respectively. While the flexural strength and flexural modulus enhanced up to 46.1% and 53.2% respectively. Besides that, DSC analysis shows that adding GnT does not alter the thermal properties of the composite with a melting point of 161.5 °C. Overall, the results confirm that the addition of graphene improves the mechanical properties of the composites. It is suggested that further research should investigate the optimal ratio of GnP, kenaf, and PLA composition in order to achieve the optimum mechanical properties so that this composite has the potential to be used in various applications.

Keywords: Kenaf fiber, Bio-composite, Polylactic acid (PLA), Graphene Nanoplatelets (GnP) and Mechanical Properties

1. INTRODUCTION

In recent years, there has been a growing emphasis on the development of sustainable materials and composites due to escalating environmental concerns and the depletion of non-renewable resources. Integrating natural fibers with synthetic polymers has become a viable method for producing high-performing, ecologically friendly composites. Kenaf fibers, derived from the Kenaf plant and Graphene Nanoplatelets (GnP), a form of carbon with exceptional properties, have garnered significant interest as potential reinforcements for polylactic acid (PLA) composites [1]. The purpose of this study is to determine the important factors related to the fabrication and characterization of kenaf and GnP in PLA composite.

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The demand for lightweight composites, especially in the automotive industry and interior building materials, puts kenaf as the primary choice of natural fiber due to its low density and impressive strength. Kenaf is a fast-growing annual plant that takes less than 6 months to reach an appropriate size to use in practical application and it belongs to the Malvaceae family [2]. Native to Africa and Asia, kenaf has been cultivated for centuries for various purposes, including food, fiber, and medicinal uses. In recent years, researchers and industries have recognized its potential as a sustainable and eco-friendly alternative to synthetic fibers in the development of composites.

The main advantage of kenaf fiber lies in its unique combination of properties. It exhibits excellent tensile strength, making it suitable for load-bearing applications, while its low density contributes to the overall lightweight nature of composites. As pollution rates and environmental conditions continue to worsen, researchers, scientists, and engineers have advised the use of natural fiber in industrial platforms including the automobile, aerospace, aircraft, marine, and packaging industries [3]. Furthermore, kenaf is biodegradable, which aligns with the growing global focus on environmentally friendly materials and sustainable manufacturing processes. The environmentally friendly low-density material would have excellent mechanical characteristics and assist in lowering the vehicle's mass, and fuel consumption, reducing wastages and emissions will contribute to a healthier environment [4]. Kenaf fiber consists of the kenaf bast and the core is composed of cellulose, hemicellulose, and lignin [5]. Figure 1 shows the part of kenaf fiber from the kenaf steam.

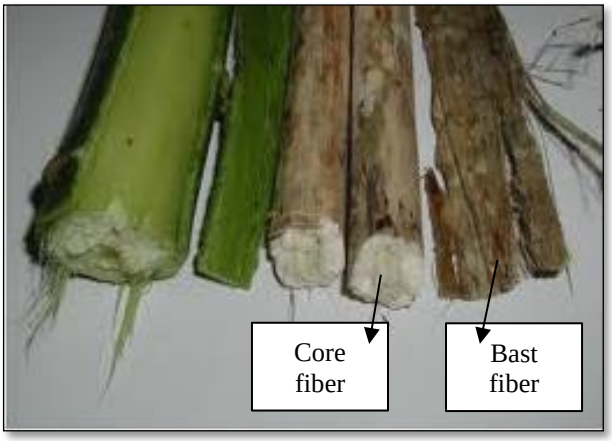


Figure 1. Kenaf Fiber

Graphene, a two-dimensional carbon nanomaterial, exhibits extraordinary electrical, thermal, and mechanical properties, making it one of the most promising nanomaterials for composite reinforcement. Graphene nanoplatelets, consisting of stacked graphene layers, can be dispersed within polymers to enhance their mechanical properties and conductivity. The high surface area and aspect ratio of GnP facilitate efficient stress transfer between the matrix and the reinforcement, resulting in improved overall composite performance. The combination of GnP with natural fibers like kenaf offers a synergistic effect, producing a multifunctional composite with unique attributes [6]. According to the prior work, adding GnP up to 5% greatly improved the composite's mechanical properties [7].

The addition of compatibilizers is a further strategy to enhance kenaf's compatibility with polymers. Compatibilizers are compounds that function as intermediaries between the polar kenaf fibers and the hydrophobic polymer matrix, facilitating better dispersion and adhesion. These compatibilizers have the ability to successfully alter the interfacial characteristics, improving the kenaf-polymer composite's overall qualities and mechanical performance [8]. The addition of graphene nanoplatelets to the kenaf and polymer composite is another solution to

address the problem. Graphene, with its exceptional mechanical properties and large aspect ratio, can act as a reinforcing agent, improving the strength and toughness of the composite. Furthermore, graphene's unique physical characteristics offer unlimited possibilities as a composite material, allowing for the enhancement of barrier properties and mechanical performance while maintaining rigidity without compromising toughness.

To maximize the mechanical properties of kenaf, researchers have explored different methods of incorporating it into polymer matrices. Among the various polymers, Polylactic acid (PLA) has gained considerable attention due to its biodegradable and renewable nature. However, achieving a strong bond between the hydrophilic kenaf fibers and the hydrophobic PLA matrix presents a significant challenge. The inherent polarity of kenaf fibers can lead to poor interfacial adhesion, resulting in reduced mechanical performance of the composite. To address this issue, researchers have turned to nanomaterials, such as graphene nanoplatelets (GnP), which have shown promising results in enhancing the interfacial bonding between kenaf and PLA.

2. MATERIALS AND METHODS

2.1 Materials

The material used to fabricate the composite comprised kenaf particles, polylactic acid (PLA) resin, and Graphene Nanoplatelets (GnP). Kenaf core fiber in the form of particles with a density of 1.3 g/cm^3 is used in sample preparation. The core is the spongy tissue pitch that lies beneath the plant bark and constitutes 60% of the total kenaf steam [9]. Table 1 shows the percentage of chemical composition in kenaf core fiber [10].

Table 1 The Percentage of Chemical Composition in Kenaf Core Fiber

No.	Chemical Composition	Percentage of Composition (%)
1	Hemicellulose	20.3–21.5
2	Cellulose	31-72
3	Lignin	8-19
4	Pectin	3-5

The biodegradable polymer matrix PLA, in a pallet form, was used as the binding agent for the composite fabrication. Its appropriate molecular weight and melt flow index make it a suitable matrix for this study. Figure 2 illustrates the different fractions of kenaf core fiber and PLA in pallet form. Meanwhile, Table 2 shows the specification of PLA pallets that are used in this study.

(a) (b)

Figure 2. (a) Different Fraction of Kenaf Core Fiber [11] and (b) PLA pallet

Graphene Nanoplates (GnP) with a density of 2.26 g/cm^3 and a surface area of 500 m^2/g were obtained from the laboratory at UiTM Shah Alam. The specific surface area characteristic makes it suitable as the reinforcing filler and will contribute to an outstanding mechanical characteristic of the compound.

Table 2 The specification of PLA pallet

Properties	Unit
Density	1.25 g/cm^3
Melting point	160 ℃
Melt flow rate	10 - 12 g/10min
Yield strength	55 MPa
Elongation at break	2%
Impact strength	44 kJ/m^2
Glass transition temperature	54 ℃

Sources: Shenzun Esun Co. Ltd.

2.2 Methods

2.2.1 Sample Preparation

The fabrication of the polylactic acid/kenaf particles/Graphene Nanoplatelets (PLA/kenaf/GnP) composites involved several steps in order to establish homogeneity in the composite material and also to guarantee the uniform dispersion of GnP inside the matrix will achieve. The compositions of composite samples in percentage were set at (95/5/0), (85/15/0), (80/20/0), (70/30/0) and (85/10/5) represented by (PLA/kenaf/GnP). Each material composition is weighed according to a specific percentage using the weighing balance. The feedstocks of polymeric-based materials were prepared by mechanically mixing PLA pellets with kenaf particles and GnP for 1 hour at 190˚C by using a VT Sigma Blade mixer machine. Figure 3 illustrates the hot press machine and cruncher machine that is used for composite fabrication while Figure 4 shows the dumbbell shape mould that is used for the fabrication of samples for the testing. In order to reduce differences and produce a consistent composite sample for the precise testing result, the preparation method was carefully devised.

(a) (b)

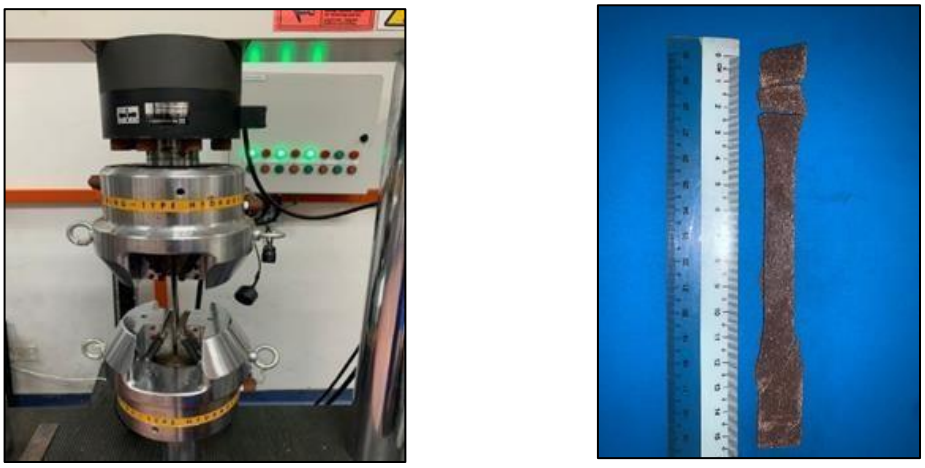
Figure 3. (a) Hot Press Machine and (b) Cruncher Machine

Figure 4. Dumbbell Shape Mould

The feedstocks were then crushed using the cruncher machine until it became a powder. Subsequently, the powder mixture was compressed using the hot press machine for 6 minutes at 180℃ under 2MPa pressure. The samples were cooled for 30 minutes to maintain their shape and minimize the defect.

2.2.2 Sample Analysis

Mechanical testing was conducted to determine the tensile and flexural properties of the composite. Samples were prepared with a specific size of 165 x 13 x 4 mm^3 according to ASTM D638 for tensile test and ASTM D790 for flexural test. 5 samples were prepared for each composition in order to get an accurate result. The tensile and flexural test was conducted using the universal testing machine at room temperature with a constant crosshead speed of 1mm/min. Besides that, the gauge length for the tensile was set at 50 mm while the support span for the flexural test was set at 60mm. Figure 5 illustrates the Shimadzu Universal Testing Machine and sample after undergoing the tensile test.



(a) (b)

Figure 5. (a) Shimadzu Universal Testing Machine and (b) Sample After the Tensile Test

DSC was used to assess the glass transition temperature (Tg), melting point, degree of crystallinity, and oxidation resistance of the constituent materials in order to ascertain the thermal behaviour of the composite. Five samples with weight of 5–10 mg, were heated at a rate of 10˚C per minute from room temperature until 300˚C. The temperature was maintained at 200˚C

for 5 minutes before being reduced to room temperature at a rate of 5˚C per minute. The sample was put in the DSC pan, and the rate of heating was 25 °C/minutes and subjected to the nitrogen flow. Initially, the samples were scanned from 80 to 300 °C and subsequently cooled to 80 °C to 300 °C. After that, the sample was cooled to 80 °C before being reheated to 300 °C in a second cycle. The highest region of the endothermic melting peak was selected as the melting temperature, and during the second heating scan, the temperature change was an inflection temperature from the baseline [12]. Melting temperature and glass transition were obtained from differential scanning calorimetry. Figure 6 below shows the Mettler Toledo that provides successful differential scanning calorimetry analysis.

Figure 6. Testing Equipment of DSC (Mettler Toledo)

3. RESULTS AND DISCUSSION

3.1 Tensile Properties

The comparison of tensile strength for 5 compositions of (PLA/kenaf/GnP) samples represented by (95/5/0), (85/15/0), (80/20/0), (70/30/0), and 85/10/5 shown in Figure 7 below. The tensile strength of the composite was determined by the maximum stress that the sample could sustain before it broke [13]. From the figure, the composition of 85% of PLA, 10% of Kenaf, and 5% of GnP exhibits the highest tensile strength which was 3.12 MPa compared to other compositions that do not contain the GnP. This indicates that the addition of GnP significantly improves the composite's mechanical properties. Furthermore, the presence of GnP encourages stronger interfacial interaction between the PLA matrix and kenaf fiber. This will strengthen the bonding between the constituent parts of the composite structure, lower stress concentration, and stop the crack from starting and spreading. This finding was supported by previous research which indicates that decent distribution will lead to a more uniform stress distribution [14]. The result of the PLA/Kenaf composite also shows that reducing the percentage of PLA from 95 to 70 % will increase the fiber content from 5 to 30% will cause a decrease in tensile properties attributed to the increase of porosity [15].

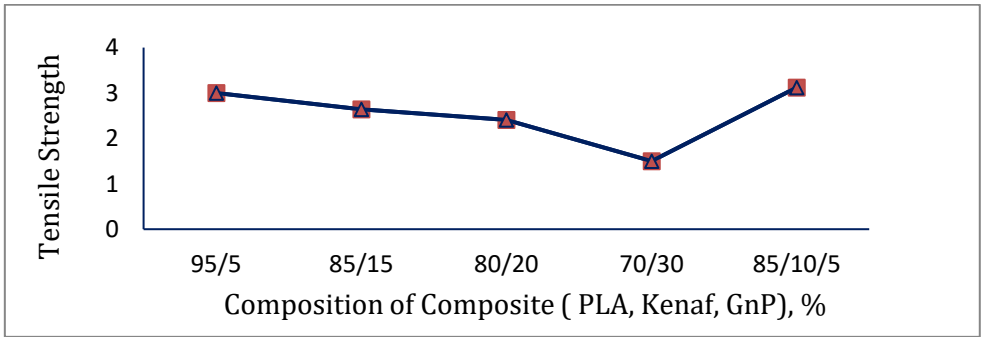


Figure 7. Tensile Strength of (PLA/Kenaf/GnP) Composite at different Composition

Meanwhile, the tensile modulus shows that the kenaf PLA composites with 5% GnP exhibited the highest tensile modulus which is 2.18GPa as illustrated in Figure 8. In comparison for Kenaf PLA composites without GnP, the tensile modulus was decreased by decreasing the percentage of PLA matrix caused by the insufficient wetting of the fibers by the matrix leading to agglomeration and hindering stress transfer [16].

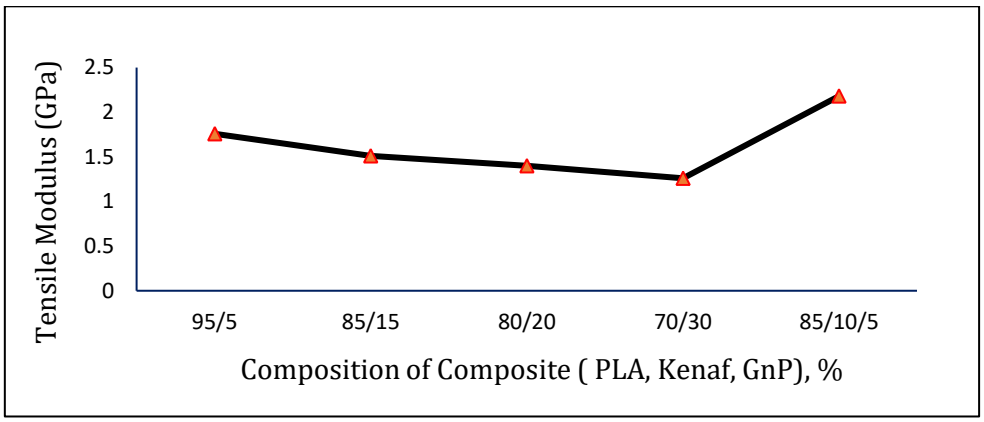


Figure 8. Tensile Modulus of (PLA/Kenaf/GnP) Composite at different Composition

3.2 Flexural Properties

As shown in Figure 9 and Figure 10 with addition of 5% GnP in the composite composition gives the highest flexural strength which is 23.96 MPa compared to the others. This is supported by a previous study that mentioned the addition of 5% weight GnP will improve the flexural properties of the composite [7]. Besides that, the increase of kenaf content will also decrease the strength of the composite. This indicates that the tensile and flexural characteristics of the composite are similar for the same composition. Lack of bonding might result in poor stress transmission and decrease the flexural properties [17]. Therefore, for applications that need greater strength and stiffness, further optimisation process of the composite composition must be performed to improve the flexural strength.

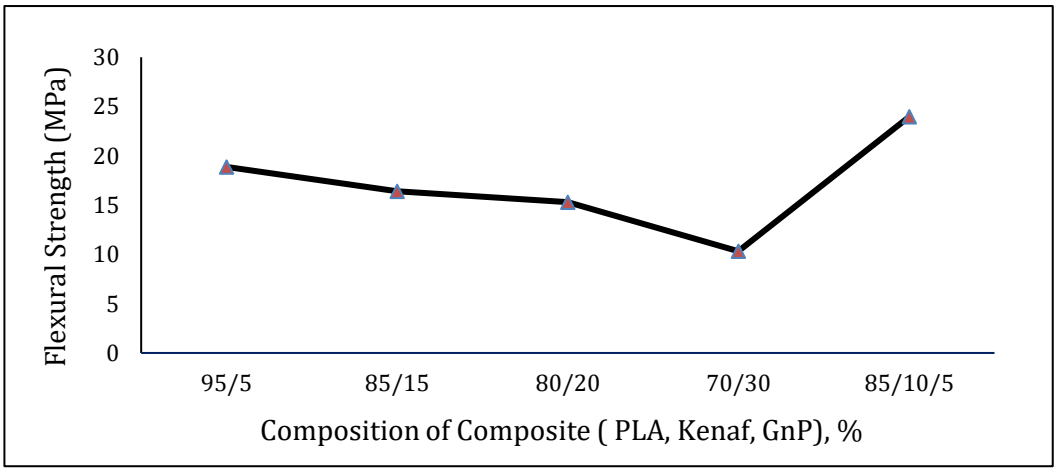


Figure 9. Flexural Strength of (PLA/Kenaf/GnP) Composite at different Composition

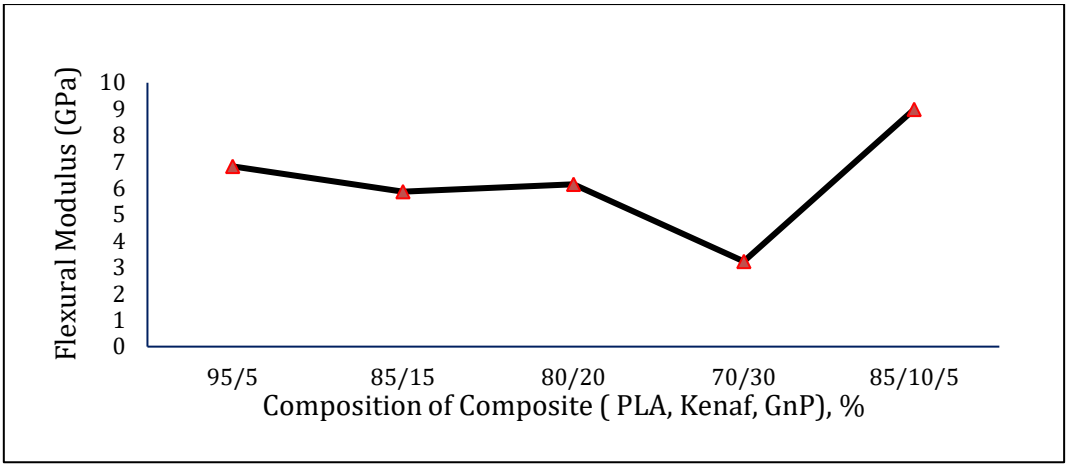


Figure 10. Flexural Modulus of (PLA/Kenaf/GnP) Composite at different Composition

3.3 Differential Scanning Calorimetry (DSC)

The data obtained from DSC analysis for all compositions of the composite was summarized in Figure 11. DSC is a study on the thermal properties of a material that aims to determine its glass transition temperature (Tg), melting point (Tm), crystalline phase (Tc), and oxidation level. Different compositions of kenaf, PLA, and graphene nanoplatelets can lead to varying interactions and arrangements of molecules within the composite. These interactions affect the polymer chain mobility and the overall behaviour of the composite.

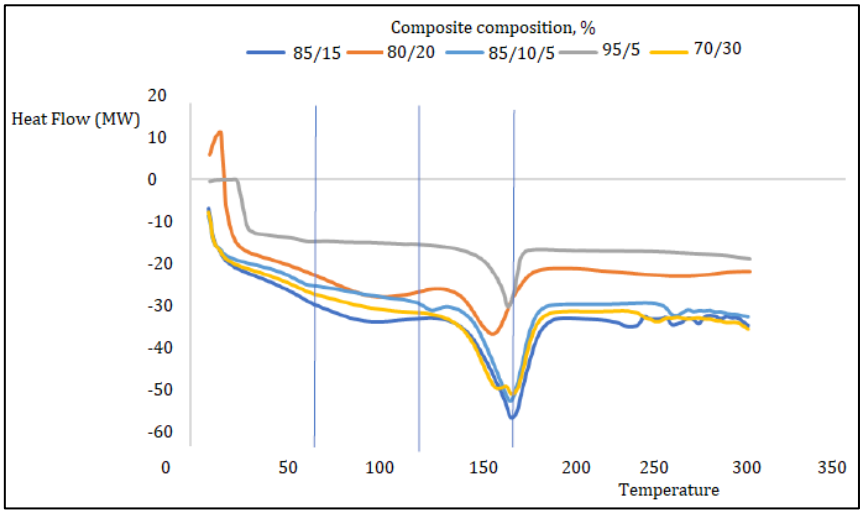


Figure 11. DSC Analysis

The data obtained based on the endothermic peak, it is found that the sample with composition of 85/15 (PLA/kenaf) and 85/10/5 (PLA/kenaf/GnT) has a melting point at a temperature of 161.5°C. The degree of crystallinity in each component and the composite as a whole can affect the energy required for melting. The finding indicates that the highest crystallinity can result in higher Tm values. This happened because the interaction between the reinforcement agent which is kenaf fiber and the PLA matrix affects the crystallization process and Tc values. The presence of GnP can further affect the interfacial interactions and influence the molecular interactions and arrangement of the chain in composite that contribute to the kinetics of crystallization [18]. Overall, the addition of GnT as a reinforcing filler does not alter the heat properties of the samples.

4. CONCLUSION

In conclusion, the research on the characterization and development of kenaf and graphene nanoplatelets in polylactic acid composites has demonstrated that the addition of graphene nanoplatelets significantly enhances the mechanical properties of kenaf/PLA composites. Throughout the study, the tensile strength and flexural properties of the composites improved considerably compared to those without GnP reinforcement and also exhibited favourable thermal properties. The findings underscore the potential of GnP as a promising reinforcement material for eco-friendly composite applications. Besides that, the addition of GnT does not alter the thermal properties of the composite but significantly enhances the mechanical properties of the resulting composite. The successful incorporation of graphene nanoplatelets into kenaf/PLA composites opens up new possibilities for sustainable materials with enhanced performance characteristics. Recommendation for further study in this area, further research should investigate the optimal ratio of GnP, kenaf, and PLA composition in order to achieve the optimum mechanical and thermal properties so that this composite has the potential to be used in various applications.

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