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The Effect of Polysulfone-nanosilica Coating on Mechanical Properties of Kenaf Fibre-Reinforced Polymer Composites

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Abstract

Natural fibre-reinforced polymer composites have gained significant popularity in various engineering applications, replacing traditional synthetic fibre composites. Due to their desirable characteristics, these composites find extensive use across diverse sectors. This study explores the potential of kenaf fibres as reinforcement material in polymer composites. The kenaf fibres are laminated with polyvinyl ester resin, forming a plant-based fibre-reinforced polymer (FRP) composite. Additionally, the research investigates the impact of a thermoplastic film namely polyethersulfone (PES), on the mechanical performance of the kenaf fibre-reinforced polymer composites. PES, a versatile thermoplastic material, holds promise for enhancing the composite's properties. The fabrication involves a compression moulding technique, where polyvinyl ester resin acts as the adhesive agent, effectively bonding the PES thin film with the kenaf fibres. To comprehensively assess the mechanical performance and durability of the thermoplastic coatings, the composites underwent a series of tests: tensile, flexural, interlaminar shear strength (ILSS) and impact tests. Remarkably, the study reveals that the incorporation of PES coating and PES-nanosilica coating demonstrated positive effects on the mechanical properties of the kenaf FRP composites, leading to notable enhancements in flexural, tensile, impact, and interlaminar shear strength. Introducing nanosilica particles yields further improvements, surpassing the benefits of the PES-based coating alone. The findings from this research emphasise the potential of PES coating and nanosilica in enhancing the mechanical performance of kenaf fibre-reinforced polymer composites. These results contribute to the domain of sustainable engineering materials, providing valuable insights for developing and optimising natural fibre-reinforced composites in various industrial applications.

1. Introduction

In recent years, natural fibres have been used as reinforcement in polymeric composites because of their good properties and the advancement into an environmentally friendly alternative for replacing synthetic fibre. Natural fibres have gained significant attention as eco-friendly alternatives to conventional fibres for compositional reinforcement. Natural fibre-reinforced polymer composites are now widely used in engineering applications to replace synthetic fibre-reinforced polymer composites.

kenaf is a natural fibre used for centuries in various applications. In recent years, there has been growing interest in using kenaf fibres to reinforce polymer composites. Kenaf fibres offer several advantages over other natural fibres, including high strength, stiffness, and toughness. They are also relatively inexpensive and environmentally friendly [1]. However, kenaf fibres have a high surface energy, which can lead to poor adhesion between the fibres and the polymer matrix. This can reduce the mechanical properties of the composites [2]. One way to improve the adhesion between the fibres and the matrix is to coat the fibres with a thermoplastic nanosilica layer. Nanosilica is a type of nanomaterial that has been shown to improve the mechanical properties of composites [3].

Therefore, this study focuses on developing kenaf fibres coated with PES and the effect of the addition of nanosilica on the mechanical performance of kenaf fibre-reinforced polymer composites. This study aims to enhance the mechanical properties of kenaf fibre-reinforced polymer composites by understanding how adding PES-nanosilica coating influences their tensile strength, flexural strength, impact resistance, and interlaminar shear strength.

1.1 Kenaf Fibre-Reinforced Polymer

kenaf is a bast fibre that is extracted from the stem of the Hibiscus cannabinus plant [4]. It is a natural fibre that is renewable, biodegradable, and sustainable. Kenaf fibres have a high tensile strength and modulus, making them a promising reinforcement material for composites. The fibre possesses high tensile strength, good stiffness, and low density, making it suitable for reinforcement applications [5]. Additionally, kenaf fibres have low cost, abundant availability, and biodegradability, making them attractive for sustainable composite materials. Various processing techniques have been employed to extract and prepare kenaf fibres for composite applications. These techniques include retting, decortications, and mechanical extraction. Retting involves the removal of non-fibre components from the plant, while decortication separates the bast fibres from the core. Mechanical extraction methods, such as milling and hammering, obtain the fibres in the desired form and size [6].

kenaf fibres are widely used as reinforcements in polymer composites due to their excellent mechanical properties and environmental benefits. These composites find applications in diverse industries, including automotive, construction, aerospace, and packaging. Various surface modification techniques have enhanced the interfacial adhesion between kenaf fibres and the polymer matrix. These techniques include chemical treatments, such as alkali treatment, acetylation, and silane coupling agents. The modified surface improves the compatibility between the hydrophilic fibres and hydrophobic polymer matrix, leading to enhanced mechanical properties of the composites [7].

1.2 Polyethersulfone For Thermoplastic Coating

Polyethersulfone (PES) is a high-performance thermoplastic polymer that belongs to the family of sulfone polymers. Polyethersulfone (PES) is known for its excellent mechanical properties [8]. PES coatings can improve the mechanical performance of various substrates, including metal, plastic, and composite [9]. Polyethersulfone exhibits a unique combination of properties, making it highly desirable for engineering applications. It possesses excellent thermal stability, with a glass transition temperature (Tg) around 225°C, enabling it to withstand elevated temperatures. PES is known for its high strength and stiffness, good chemical resistance, low moisture absorption, and inherent flame resistance. Additionally, it offers exceptional dielectric properties, making it suitable for electronic and electrical applications [10].

PES can be processed using various techniques, such as injection moulding, extrusion, blow moulding, and thermoforming. Its high melt strength and good processability allow it to produce complex shapes and intricate parts [11]. Additionally, PES can be reinforced with various fillers and fibres to enhance its mechanical properties for specific applications [12]. Polyethersulfone has extensive use in many industries due to its lightweight, high strength, excellent dielectric properties and high-temperature resistance. PES is also a matrix material in composite materials to improve their mechanical and thermal properties [13]. It has been successfully used in fibre-reinforced composites, where it enhances the strength and stiffness of the composites while maintaining their lightweight nature. The interfacial bonding between PES and various reinforcing materials, such as glass, carbon, and nanoparticles, has been investigated to optimise the composite performance [14].

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1.3 Nanosilica As a Reinforcing Agent

Nanosilica (NS), also known as nano-sized silicon dioxide or silica nanoparticles, has gained significant attention in various fields due to its unique properties and diverse applications. Nanosilica possesses unique properties attributed to its nanoscale dimensions. It exhibits a high specific surface area, which enhances its reactivity and interaction with other materials. The high surface area also contributes to its improved mechanical, thermal, and optical properties [15]. Additionally, nanosilica exhibits excellent dispersion in different matrices due to its small particle size, enhancing material performance [16]. The small particle size of nanosilica allows for improved dispersion within the polymer matrix, leading to enhanced mechanical properties.

Nanosilica can increase the stiffness of a coating by up to 50%. This is due to the high aspect ratio of the nanoparticles, which means that they have a large surface area to volume ratio. Nanosilica can also increase the toughness of a coating by up to 30%. The increased toughness of a nanosilica-reinforced coating is due to the nanoparticles' ability to act as crack arrestors. When a crack forms in a nanosilica-reinforced coating, the nanoparticles can trap the crack and prevent it from propagating [17]. In recent years, nanosilica has been extensively investigated as a nanofiller in polymer composites. Incorporating nanosilica into polymer matrices enhances their mechanical properties, such as tensile strength, modulus, and hardness. It also improves thermal stability, flame retardancy, and barrier properties. Moreover, nanosilica acts as a reinforcement agent, improving the overall performance of polymer composites [18].

1.4 Polyvinyl Ester (PVE) Resin

As the matrix material, the polyester resin plays a crucial role in holding and bonding the reinforcement fibres, forming a composite structure with enhanced mechanical properties. The resin is a toughening agent, improving the fibre composites' overall strength, stiffness, and impact resistance [19]. Combining the polyester resin as the matrix toughener and the woven kenaf fibres as reinforcement materials provides a synergistic effect, leading to the development of high-performance kenaf fibre-reinforced polymer composites [20]. Studies have demonstrated that polyester resins offer good adhesion to a wide range of reinforcing fibres, including natural fibres like Kenaf, resulting in improved interfacial bonding and load transfer [21]. The toughness and flexibility of polyester resin allows it to absorb and disperse energy during loading, contributing to the composite's impact resistance and fracture toughness [22].

Moreover, polyester resin is known for its cost-effectiveness and ease of processing, making it a favourable choice for composite fabrication [23]. Its low viscosity enables thorough impregnation of the reinforcement fibres, ensuring uniform distribution and reduced void content within the composite structure [24]. Proper polyester resin curing during fabrication is crucial to achieve optimal mechanical properties and avoid potential defects, such as voids and delamination. Several researchers investigated the mechanical performance of polyester-based kenaf fibre-reinforced composites and reported improvements in tensile strength, flexural strength, and impact resistance with the addition of polyester resin [25].

In conclusion, this study's significance lies in its potential contributions to materials engineering, sustainability, and innovation while providing valuable learning experiences for the students. The findings may pave the way for developing advanced composites with improved mechanical properties, promoting the adoption of environmentally friendly alternatives in diverse engineering applications.

2. Methodology

2.1 Materials Preparation

The kenaf fibre in this study uses a 0.15 mm diameter kenaf fibre rope. The fibres were then carefully cleaned, straightened, and aligned to ensure uniformity and consistency in the woven kenaf sheets. The kenaf fibre needs to be woven in a mat or woven Kenaf. The woven kenaf fibre was the reinforcement material in fabricating kenaf fibre-reinforced polymer composites. Then, the PES thin film preparation process was initiated with the formulation of the doping solution. For the composite thin film of Polyethersulfone (PES), a specific Dimethylacetamide (DMAc) ratio of PES was used, 74:26 wt.%. The PES thin film served as the coating material for the kenaf fibre-reinforced polymer composites, imparting enhanced properties and protection to the composite structure. DMAc is a highly effective and versatile solvent that dissolves various organic and inorganic compounds, including PES. The high solvency power of DMAc facilitated the uniform dispersion of PES powder and the formation of a homogenous PES coating solution. Using DMAc as the solvent ensured the successful application of the PES coating onto the kenaf fibre-reinforced polymer composites. The properties of the PES powder used are shown in Table 1.

In the case of PES-nanosilica thin film, the ratio of DMAc to PES to SiO_2 (Silicon Dioxide) was adjusted to 74:25:1 wt.%. PES was added to DMAc to create the casting solution and stirred at 60 °C for 24 hours until fully dissolved. Subsequently, the solution underwent a degassing step to remove any trapped air bubbles. A phase inversion method was employed for casting the thin film. The PES-nanosilica solutions were poured onto a clean and dry glass plate. The PES-nanosilica solution was spread on the glass plate using a glass rod. The thickness of the thin film was maintained using tape placed on both sides of the glass plate. The process is simplified in Fig. 1.

Table 1 *Mechanical and thermal properties of polyethersulfone (PES) powder*

Properties	Property Value
Tensile Modulus	2.65 GPa
Tensile Stress at Yield	85 MPa
Tensile Strain at Yield	6.9 %
Heat Deflection Temperature (HDT)	207 °C

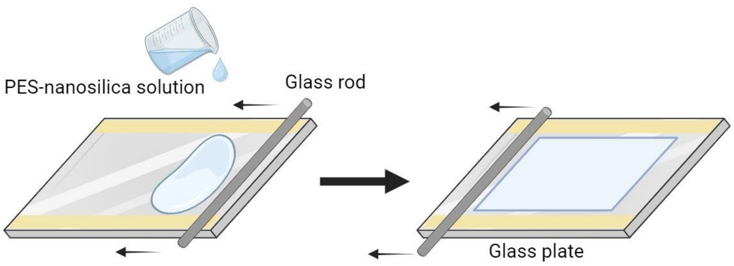

Fig. 1 *The initial process of preparing PES-nanosilica thin film*

The glass plate and the thin film were immediately immersed in a solvent-free coagulation bath maintained at 25 ± 2 °C, consisting of Deionized (DI) water. This allowed for the phase inversion process to occur, resulting in the formation of the thin film. After coagulation, the newly formed thin film was transferred to a fresh DI water bath, where they were left for 24 hours to complete the phase inversion process. The thin film was then thoroughly washed with DI water and left to dry at room temperature. Combined with the PES powder and DMAc solvent, the nanosilica particles improved the coated composites' mechanical properties and interfacial adhesion [26]. These nanosilica particles were chosen for their high surface area and reinforcing effects. The surface area, pore volume, and particle size of the nanosilica used are shown in Table 2.

Table 2 *The surface area, pore volume and particle size of nanosilica*

Surface area	Pore volume	Particle size
90.38 m^2/g	0.3447 cm^3/g	228.4 nm

A PES and PES-nanosilica thin film was prepared separately and used as a control experiment for comparison purposes. The dry-wet phase inversion technique was specifically employed to fabricate the thin film. This process ensures the creation of well-structured and uniform thin films with improved performance characteristics, making them suitable for their intended applications [27].

2.2 Fabrication of Kenaf Fibre-Reinforced Polymer Coated with PES-Nanosilica Thin Film

A polyvinyl ester (PVE) resin mixture was prepared to fabricate the kenaf fibre composite, using a 1:4 ratio. The PVE and organic peroxide mixture were thoroughly blended until a slight colour change indicated the start of the stirring process. Then, two layers of the kenaf woven fibre were carefully placed, and the PVE mixture was poured over it. Once the resin mixture was poured, one sheet of PES thin film was placed on top of the kenaf fibre layer. The sequence of the kenaf fibre composites is shown in Fig. 2.

Subsequently, a second layer of the Polyvinyl mixture was poured over the PES thin film. The same steps were repeated for the system involving the PES-nanosilica thin film. After this process, the kenaf fibre composite with PES and PES-nanosilica coating was successfully fabricated. PES and PES-nanosilica coatings hold great potential in enhancing the composite's mechanical properties and overall performance, making it a promising eco-friendly material for various engineering applications.

2.3 Kenaf FRP Composites Systems

The primary constituents of the first composite system (K/PVE) are kenaf fibres in Polyvinyl ester resin. The kenaf fibres are impregnated and bonded with the Polyvinyl resin during the composite fabrication, forming a

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homogenous structure. In the second composite system (K/PES/PVE), an additional layer of polyethersulfone (PES) coating is applied on top of the K/PVE composite. In the last composite system, the third composite system (K/PES-NS/PVE), nanosilica particles are added to the PES solution to create a nanocomposite structure. Nanosilica is a reinforcing filler, providing enhanced mechanical properties due to its unique nano-sized properties.

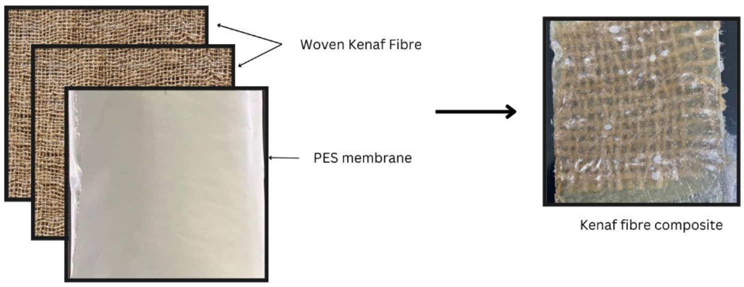

Fig. 2 *The sequence of the kenaf fibre composites*

2.4 Tensile Test

The tensile test was performed following the ASTM D5766 standard. The crosshead speed was set to 2 mm/min, ensuring a consistent and controlled rate of loading applied to the kenaf composite specimens. This moderate crosshead speed allowed for accurate data collection and analysis of the mechanical properties. Kenaf composite specimens with dimensions of 250 × 25 × 4 mm were prepared for this test, as shown in Fig. 3.

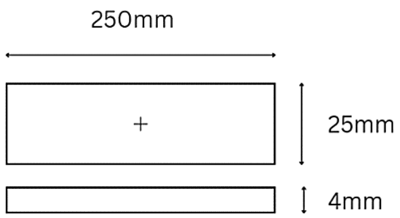

Fig. 3 *Specimen prototype for tensile test based on ASTM D5766*

2.5 Flexural Test

The flexural test was conducted using the Instron 3382 Universal Testing Machine, following the ASTM D790 standard. To maintain consistency, the span length to sample thickness ratio was set at 16:1. The crosshead speed of the Universal Testing Machine was set at 2 mm/min. This controlled loading rate gradually applied force to the composite specimens during the test. The composite specimens with dimensions of 80 × 13 × 4 mm were prepared for each system, as shown in Fig. 4.

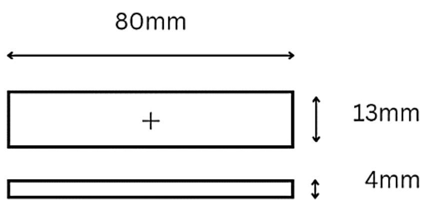

Fig. 4 *Specimen prototype for flexural test based on ASTM D790*

2.6 Interlaminar Shear Strength (ILSS) Test

The flexural test was conducted using the Instron 3382 Universal Testing Machine, following the ASTM D790 standard. To maintain consistency, the span length to sample thickness ratio was set at 16:1. The crosshead speed of the Universal Testing Machine was set at 2 mm/min. This controlled loading rate gradually applied force to the composite specimens during the test. The composite specimens with dimensions of 80 × 13 × 4 mm were prepared for each system, as shown in Fig. 4.

The interlaminar shear strength (ILSS) test followed the ASTM D2344 standard with 36 × 12 × 4 mm dimensions, ensuring consistency in sample size, as shown in Fig. 5. The crosshead speed was set at 2 mm/min, providing a controlled and uniform loading rate during the test. The interlaminar shear strength test provided crucial insights into the composite's resistance to shear forces between its layers. This test was essential in evaluating the effectiveness of the PES and PES-nanosilica coatings in enhancing the interlaminar bonding and interfacial adhesion within the polymer composites.

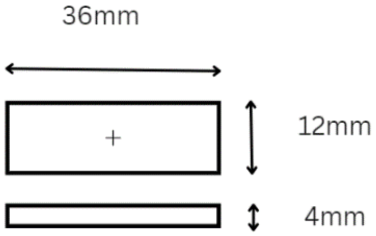

Fig. 5 *Specimen prototype for the ILSS test based on ASTM D2344*

2.7 Impact Test

The impact test was carried out following the ASTM D7136 standard. Composite specimens with dimensions of 50 × 50 × 4 mm, as shown in Fig. 6, were prepared for the test, ensuring consistency in sample size. The hemispherical tip impactor, with a diameter of 13 mm, was selected for the test. The impactor was aligned with the centre of the specimen. The deflection and energy absorption characteristics provided valuable insights into the composite's ability to withstand sudden impact loads.

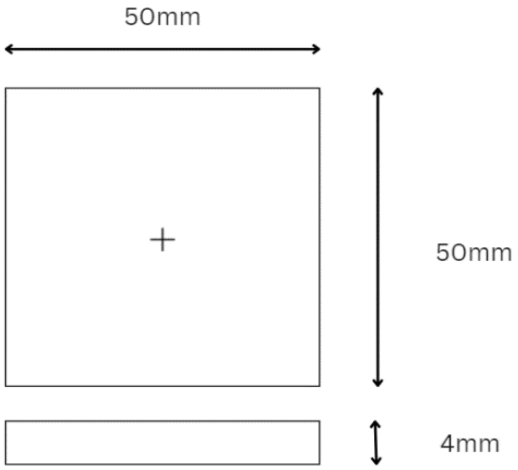

Fig. 6 *Specimen prototype for the impact test based on ASTM D7136*

3. Results and Discussion

3.1 Impact Test

The tensile properties of kenaf fibre reinforced polymer with PES-nanosilica are presented in Table 3. Tensile modulus was evaluated to measure material stiffness and its ability to withstand tensile forces. Table 3 shows that kenaf with PES-nanosilica coating exhibited the highest tensile modulus at 1.91 GPa, followed by kenaf with PES coating at 1.71 GPa and K/PVE with 1.68 GPa. Kenaf with PES-nanosilica coating also demonstrated the highest tensile strength of 18.998 MPa. The assessment of tensile strain at break (%) showed that the highest value recorded was 0.965%.

Table 3 *Tensile properties of kenaf fibre reinforced with PES and nanosilica*

Composite Systems	Tensile Modulus (GPa)	Tensile Strength (MPa)	Tensile Strain at Break (%)
K/PVE	1.68 ± 0.072	14.238 ± 1.753	0.921 ± 0.032
K/PES/PVE	1.71 ± 0.081	16.436 ± 3.365	0.942 ± 0.233
K/PES-NS/PVE	1.91 ± 0.096	18.998 ± 3.928	0.965 ± 0.151

These findings underscore the positive influence of incorporating PES-nanosilica coating on the tensile behaviour of the kenaf Fiber Reinforced composites. This enhancement is evident in the stress-strain curves (Fig. 7), with steeper curves indicating a higher modulus. Although the obtained tensile modulus for kenaf is slightly lower than the expected range (typically between 5 GPa and 9 GPa), the study's trend indicates an improvement in the material's mechanical properties due to nanosilica inclusion. It is worth noting that various factors, such as fibre quality, fibre alignment, and testing methodology, may contribute to the slight deviation from the expected tensile modulus value.

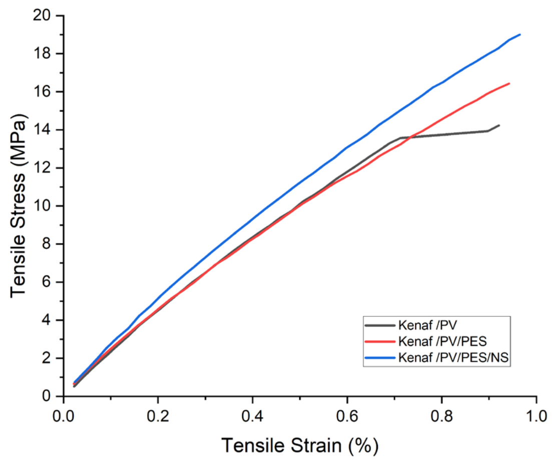

Fig. 7 *Tensile stress against tensile strain*

PES-nanosilica coating in the kenaf fibre-reinforced polymer composites improved tensile properties, signifying their potential to enhance the material's overall performance. These findings contribute valuable insights to developing high-performance composite materials with broad applications in various engineering fields.

3.2 Flexural Properties

Table 4 presents the flexural properties of different kenaf fibre-reinforced polymer composite systems. Among the samples, the highest flexural modulus of 4.446 GPa is achieved by the kenaf composite with PES-nanosilica coating, indicating its superior resistance to deformation when subjected to bending forces. Additionally, the table includes the flexural strength, which represents the maximum stress a material can withstand before failure under bending. In this study, the kenaf FRP composite with PES-nanosilica coating exhibits the highest flexural strength of 61.596 MPa, highlighting its superior load-carrying capacity compared to the other samples.

Table 4 *Flexural properties of kenaf fibre-reinforced polymer composites with PES and nanosilica*

Composite Systems	Flexural Modulus (GPa)	Flexural Strength (MPa)	Flexural Strain at break (%)
K/PVE	2.745 ± 0.873	34.3035 ± 10.90	1.8228 ± 0.53
K/PES/PVE	3.706 ± 0.587	56.6011 ± 17.82	1.6885 ± 0.65
K/PES-NS/PVE	4.446 ± 0.838	61.5960 ± 19.93	2.3266 ± 0.99

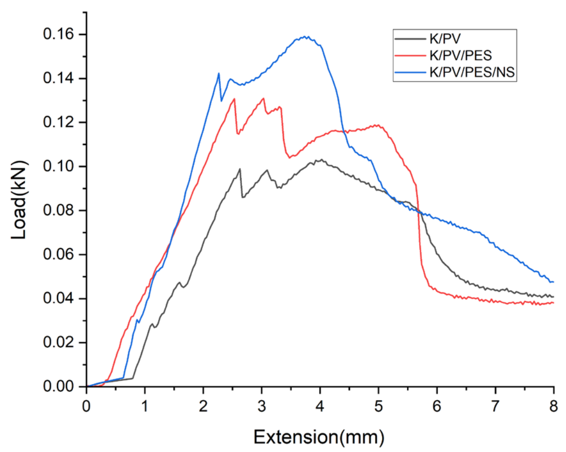

Fig. 8 *Load versus extension*

The kenaf FRP composite with PES-nanosilica coating demonstrated a flexural strain, the deformation a material undergoes before fracture during bending of 2.33%, indicating its ability to withstand significant deformation before failure. Table 4 highlights the enhanced mechanical performance of the kenaf FRP composites with PES-nanosilica coating, making them a promising option for various engineering applications that require high stiffness, strength, and resilience under bending loads.

The graph in Fig. 8 illustrates the load versus extension behaviour during the flexural test for different kenaf FRP composite systems. The graph shows that the kenaf FRP composite with PES-nanosilica coating exhibits the highest load-carrying capacity among all the samples, reaching a peak load of 0.157 kN. This indicates the superior ability of this composite to withstand bending forces without undergoing failure. In contrast, the other composites with different coatings and formulations show comparatively lower peak loads, signifying their relatively lower strength and load-carrying capabilities during the flexural test.

The ascending nature of the load-extension curve for each composite demonstrates the material's capacity to bear increasing loads until reaching the maximum load before fracture or failure. The graph's shape and the significant difference in peak loads between the composites indicate the positive influence of PES-nanosilica coating on enhancing the flexural strength and load-bearing capacity of the kenaf FRP composites.

3.3 Interlaminar Shear Strength Properties

The data presented in Table 5 shows that the kenaf composite with PES-nanosilica coating exhibits the highest interlaminar shear strength with a value of 15.1 Pa. The significant difference in ILSS values between the composites highlights the positive impact of incorporating PES and nanosilica on improving the interlayer bonding and overall interlaminar shear strength of the kenaf FRP composites. The ILSS measurement quantifies the interlayer bonding and the laminate's ability to withstand shear stress under loading conditions. Higher ILSS values indicate a stronger bond between the layers and enhanced resistance to shear deformation. These results confirm that the addition of nanosilica enhances the bonding and interfacial adhesion between the fibres and the matrix, leading to improved shear resistance and mechanical performance of the composites.

Table 5 *ILSS Properties of kenaf fibre-reinforced polymer composites with PES and nanosilica*

System	Energy, J	Shear Stress (MPa)	Shear Strain (%)	Interlaminar Shear Strength, (Pa)
K/PV	0.6879 ± 0.016	195.52 ± 6.18	5.951 ± 0.30	13.0 ± 0.653
K /PV/PES	0.8393 ± 0.092	216.54 ± 10.62	6.403 ± 0.99	14.4 ± 0.708
K/PV/PES /NS	1.1039 ± 0.222	226.29 ± 36.26	6.749 ± 1.68	15.1 ± 2.417

From Fig. 9, it is shown that the composite with the highest shear stress value is K/ PES-NS/PVE, reaching 226.29 MPa. The kenaf FRP composite with PES-nanosilica coating composite, with the highest shear stress, demonstrates enhanced resistance to shear forces, highlighting the positive influence of incorporating PES and nanosilica in improving the composite's interfacial adhesion and overall mechanical performance.

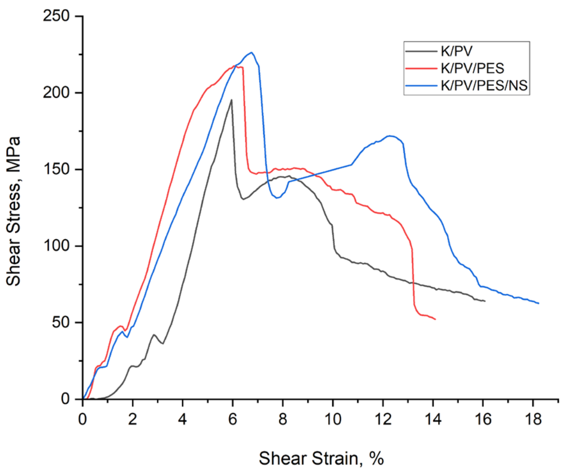

Fig. 9 *Shear stress against shear strain*

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3.4 Impact Properties

As shown in Table 6, including nanosilica in the composites resulted in the highest peak load, reaching an impressive value of 1728.4 kN. The results indicate that the presence of nanosilica significantly enhances the composite's ability to withstand impact forces, making it a potential material for applications where impact resistance is crucial. Moreover, the data indicates that the kenaf FRP composites embedded with PES-nanosilica coating displayed the highest deflection among the tested samples, measuring 3.9 mm. This significant deflection value further reinforces the impact resistance improvement by incorporating nanosilica into the composite.

Table 6 *Impact properties of kenaf fibre-reinforced polymer composites with PES and nanosilica*

Composites	K/PVE	K/PES/PVE	K/PES-NS/PVE
Peak Load-1 (kN)	1519.7 ± 156.78	1662 ± 83.62	1728.4 ± 149.39
Deflection (mm)	2.85 ± 0.53	3.86 ± 0.12	3.90 ± 0.41
Initiation Energy (J)	3.8272 ± 0.62	4.2217 ± 0.189	4.5004 ± 0.50
Propagation Energy (J)	5.4263 ± 0.61	8.5611 ± 1.64	10.16 ± 0.51
Total Energy (J)	9.2535 ± 1.24	12.7828 ± 1.83	14.6604 ± 1.02
Ductility Index	1.41	2.02	9.
Impact strength (kJ/m^2)	31.203	34.419	36.691

By effectively controlling nanosilica dispersion and interfacial bonding, the K/PES-NS/PVE composite exhibits superior energy absorption, making it a promising candidate for impact-critical applications [30]. The significant difference in energy absorption between the K/PES-NS/PVE and K/PVE composites can be attributed to the reinforcing effect of nanosilica particles. Nanosilica acts as a bridging agent, preventing crack propagation and promoting stress distribution, resulting in enhanced energy dissipation and damage resistance during impact. Furthermore, PES enhances the composite's mechanical strength and deformation resistance, contributing to the overall energy absorption capability. The successful dispersion of nanosilica and strong interfacial bonding further reinforce the composite's ability to withstand impact-induced damage, underscoring its potential for various applications requiring high energy absorption and impact resistance [31].

The graph in Fig. 10 illustrates the relationship between load and extension for the impact test conducted on different kenaf FRP composites. As shown, the highest load of 10.2 kN is achieved by the kenaf FRP composite with PES-nanosilica coating. This indicates that the presence of PES and nanosilica enhances the load-carrying capacity of the composite material during impact testing. The ability to withstand higher loads indicates the composite's improved strength and toughness, making it more resistant to impact forces and potential failure. The ascending trend in the load-extension curve for the kenaf composite with PES nanosilica coating signifies its superior mechanical properties, making it a promising candidate for impact-sensitive applications.

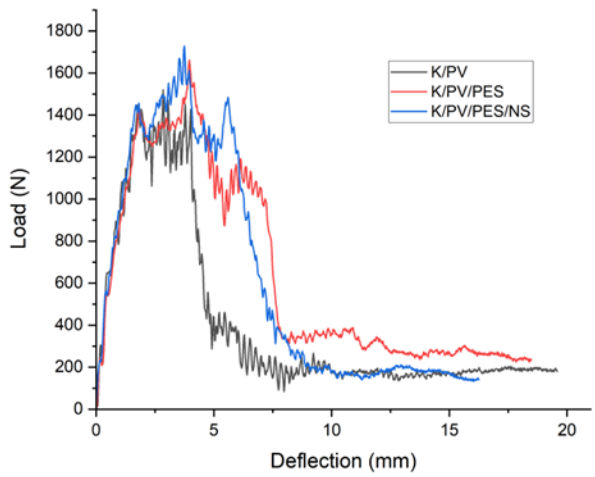

Fig. 10 *Load against deflection*

Penerbit UTHM

4. Conclusions

From the results obtained, it can be concluded that applying the PES-nanosilica coating significantly and positively affects the mechanical properties of kenaf FRP composites. Adding nanosilica particles to the PES coating further enhances the flexural strength of kenaf FRP composites. The presence of nanosilica in the PES coating significantly increases the impact resistance of kenaf FRP composites, endowing them with improved energy absorption capabilities. The enhanced impact resistance is vital for applications that involve exposure to dynamic loads or potential impact events. The interlaminar shear strength (ILSS) of kenaf FRP composites is notably improved with the addition of nanosilica in the PES coating. This improvement indicates enhanced interlayer bonding and shear resistance, resulting in stronger and more durable composite structures. The combined effects of the PES coating and nanosilica reinforcement make the kenaf FRP composites highly promising materials for various engineering applications, offering a compelling alternative to conventional synthetic fibre-reinforced composites.

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Conflict of Interest

The authors declare no conflict of interest regarding the paper's publication.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design:*** *Iyazi Shazana Mohamad, Aidah Jumahat;* ***data collection:*** *Iyazi Shazana Mohamad;* ***analysis and interpretation of results:*** *Ilya Izyan Shahrul Azhar, Ummu Raihanah Hashim;* ***draft manuscript preparation:*** *Ilya Izyan Shahrul Azhar, Aidah Jumahat, Ramzi Khiari. All authors reviewed the results and approved the final version of the manuscript.*

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