

Effect of Fibre Orientations and Nanosilica on Mechanical Properties and Ultimate Tensile Strength of Polymer Composite Materials

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Abstract

Polymer composite materials have extensively been utilised due to their superior mechanical properties. Incorporating nanosilica into the resin matrix has been demonstrated to further enhance these properties. This study investigates the ultimate tensile strength of composites made with both pure (PW) and nanosilica-enhanced Willkat resin (5NSW), examining different fibre configurations oriented at 0° and 90°. Results show that the combination of 5 wt.% nanosilica (5NSW) provides the best tensile strength properties. Increasing the nanosilica content beyond this level results in higher viscosity and agglomeration, which adversely affect the properties. Basalt (B/B) comingle fibre exhibits the highest ultimate tensile strength with 302.46 MPa, followed by glass (G/G) comingle fibre with 137.69 MPa, with the addition of 5 wt.% nanosilica. The lowest strength is obtained with Arenga pinnata (AP/AP) fibres at 25.85 MPa in 0° fibre orientation; meanwhile, it increases in strength when hybridised with basalt and glass fibres. The orientation of the fibre also has an impact on the properties of the composite, where 0° fibre orientation gives a better value than 90° fibre orientation. Additionally, the incorporation of nanosilica into the matrix enhances the overall strength of the composites.

1. Introduction

Polymer composites have been extensively utilised in engineering applications for many years, particularly in environments with extreme conditions. Researchers have focused on enhancing the performance of incorporating suitable fillers and fibres. The inclusion of nano-sized powder using appropriate techniques and procedures can significantly improve the properties of the matrix materials. Particularly, the addition of nano-sized powder can enhance the properties of the matrix, including modulus, strength, and hardness, without significantly increasing the weight of the composite due to the molecular-level reinforcement of the resin. This is because nano-sized particles exhibit a substantial surface area-to-volume ratio, enabling greater contact with the resin matrix [1]. The strong interfacial interaction between the silica particles and the resin facilitates stress transfer from the matrix to the particles, thereby improving the mechanical properties of the composite. However, the effect of varying the

percentage of nanosilica used has also been investigated by other researchers, demonstrating its potential to enhance the properties of the matrix used in a mechanical system [2], [3].

Nanosilica provides a balanced combination of reliable mechanical properties, thermal stability, barrier properties, ease of dispersion, processing flexibility, cost-effectiveness, and availability. These advantages make it an exceptional material for enhancing the characteristics of resin matrices in fibre-reinforced polymer composites, especially when compared to other types of nanosilica. The incorporation of nanosilica enhances the toughness of the composite by increasing its ability to absorb and dissipate energy during mechanical loading, thereby making it more resistant to cracking and impact [4]. Additionally, nanosilica is generally more cost-effective than other advanced nanosilica, such as carbon nanotubes or graphene, making it an attractive option for commercial applications where cost is a critical factor. Nanosilica is widely available and can be produced in large quantities, ensuring a stable supply for industrial applications. The addition of nanosilica to the matrix enhances various properties, including mechanical properties and thermal stability, making it more suitable for high-temperature applications. It also improves flame retardancy, thereby increasing resistance to fires and reducing the risk of damage or loss due to fire. Additionally, nanosilica enhances rheological properties, which is particularly beneficial for applications requiring precise material control, such as 3D printing [5]. Improvements to the matrix material enhance its mechanical properties and effectiveness in binding fibres together while transferring loads between them. Since the matrix-fibre interface is crucial for load transfer, these enhancements can significantly increase interfacial bonding, resulting in better stress distribution and reduced risk of fibre pull-out or delamination.

Fibre and yarn are two types of fibrous materials that have different structures and properties. Fibre refers to single strands of material, while yarn refers to a combination of more than one fibre. Fibres are usually very thin and can be either short or long [6], [7]. In contrast, yarn is made by twisting or spinning fibres together to form a continuous strand. The thickness and strength of the yarn depend on the number of fibres that are twisted together and the degree of twist [8]. Yarns can be made from a single type of fibre or a blend of different fibres, which tend to be stronger and more resilient. The characteristics of yarn make it more durable than individual fibres because single fibres may be prone to breakage or wear [9]. Yarn fibre composites, which integrate the benefits of yarn fibres with a matrix material, have emerged as a promising class among the various types of fibre-reinforced composites. These composites have garnered significant attention in the field of novel materials due to their exceptional mechanical properties and versatility across a wide range of applications. Natural fibres are specifically chosen for their extensive availability, ease of production, and notable material properties, such as biodegradability, low cost per unit volume, high strength, and specific stiffness. Arenga pinnata fibre, a widely recognised natural fibre, was developed to reduce the reliance on conventional fibres. These fibres are utilised in various materials, primarily in automation, military, and textiles. Additionally, they are used to manufacture fishing gear, traditional prayer headgear, brushes, brooms, roofing, and thatching materials [10], [11].

This study examines the effect of varying nanosilica weight percentages on the enhancement of matrix properties in composite materials. By identifying the optimal composition, the enhanced matrix properties are then used to reinforce different types of fibres, as well as hybrids of these fibres, to evaluate the overall improvement in performance. Additionally, the effectiveness of fibre orientation is assessed by measuring the properties of composites with fibres aligned at 0° and 90°. This comprehensive approach aims to determine how fibre direction and matrix enhancements contribute to the mechanical properties of the composite material.

2. Methodology

2.1 Sample Preparation for Pure and Cured Polymer

Different weight fractions of nanosilica powders (1 wt.%, 3 wt.%, 5 wt.%, and 7 wt.%) were measured. A magnetic stirrer was used to ensure the mechanical mixing of the nanosilica and Willkat resin, achieving a homogeneous distribution throughout the composition. The powder and resin were combined in varied proportions. The stirrer machine was set at 450 rpm and continuously mixed for 3 hours. After thorough mixing, the mixture was degassed in desiccators using a vacuum system to remove any trapped air. The degassed mixture was then poured into silicone moulds according to ASTM D638 standards for dog bone tensile testing.

2.2 Sample Preparation for FRP Composite

Three types of yarn fibre were used in the method: petroleum-based glass fibre, mineral-based basalt fibre, and plant-based Arenga pinnata fibre. The yarn fibres were twisted using a commingling machine to produce Arenga pinnata (AP/AP), glass (G/G), basalt (B/B), and hybrid fibres, which are (AP/G) and (AP/B) commingled fibres. The yarn fibres were woven to form a mat before undergoing a vacuum bagging process and hand lay-up method. The laminate was constructed using two layers of mat fibres from each group, combined with a Willkat (poly silicate-isocyanate) resin mixture containing 5 wt.% of nanosilica (5NSW). After the curing time was completed,

the FRP composite plates measured 300 mm in length and 300 mm in width. These plates were then measured and cut according to ASTM D3039 standards for tensile testing.

3. Physical and Mechanical Testing

3.1 Tensile Test

The mechanical properties of the specimens were assessed by subjecting them to uniaxial tensile testing using a Universal Testing Machine (UTM) in accordance with ASTM D638 [12] for a matrix with different weight percentages (wt.%) of nano silica composition and ASTM D3039 [13] standards for fibre-reinforced composite samples. Five (5) samples of each type were tested, for FRP composite material, with dimensions of 250 mm × 15 mm × 2.5 mm for 0° fibre orientation and 175 mm × 25 mm × 2.5 mm for 90° fibre orientation, meanwhile, for pure and cured polymer matrix, a dog-bone shape measurement is used according to the ASTM standard. The tests measured ultimate tensile strength (UTS), elongation (%), and modulus (E). The testing speed for the samples was set at 2 mm/min.

3.2 Volume Fraction of FRP Composites

Volume fraction of the five different types of composite systems was measured and calculated using two different techniques. The burnt-off or ignition loss method was used to evaluate the fibre volume fraction of basalt (B/B) and glass (G/G) composite systems. Meanwhile, the fibre volume fraction of Arenga pinnata (AP/AP), and hybrid (AP/B) and (AP/G) composites systems was determined using an Acid digestion technique. Five (5) specimens of (B/B) and (G/G) with length to diameter (l:d) ratio of 10:10 mm were prepared for conducting the burnt-off test. The specimens were weighed to the nearest 0.0001g and placed in a ceramic crucible. After this, a crucible was placed into a Carbolite muffle furnace. The furnace was heated at 5°C/min up to 500°C and held at this temperature for an hour. Once the burning process was completed, the specimen was put in a desiccator and allowed to cool to a room temperature. Finally, the remaining weight was measured, and the volume fraction was calculated. Acid digestion was conducted in accordance with ASTM D3171-11. Specimens for (AP/AP), (AP/B), and (AP/G) systems were prepared by cutting the plates into 20 mm × 20 mm × 2.5 mm dimension and a minimum weight of at least 1.0000 g. Five specimens were tested for each composite system. The reinforcement, matrix, and void content were computed using the ASTM D3171-11. This acid digestion approach was conducted because of Arenga pinnata fibre cannot be analysed using the burn-off method, as it burns completely during the process.

4. Microstructure Measurement

4.1 Characterisation of FRP Composites Using Scanning Electron Microscope (SEM)

The surface morphology of the FRP composite was examined using an analytical Scanning Electron Microscope (SEM), operating at a voltage of 5.0 kV and a working distance of 10.5 mm. Microscopic images of the FRP composite were captured at magnifications of 27X, 50X, and 300X. Prior to SEM analysis, the samples were coated with a 5 nm-thick layer of gold using an automated fine sputter coating machine to enhance conductivity and improve image quality.

5. Results and Discussion

5.1 The Ultimate Tensile Strength of Pure and Cured Polymer

Fig. 1 displays the tensile properties of Willkat resin with varying percentages of a nanosilica (NS) additive. The parameters measured are Young's Modulus (E, GPa) represents the stiffness of the material. Ultimate Tensile Strength (UTS, MPa), is the maximum stress a material can withstand before it breaks. The value of strength increases consistently with higher NS content, with the most significant increases at 5 wt.% and 7 wt.% of NS. Variability increases at higher wt.% of NS content. The data is consistent with small error bars. The incorporation of nanosilica powder at varying weight percentages significantly enhances the mechanical properties of the matrix [14], [15]. Fig. 2 shows that the value of Young's Modulus increases with increasing nanosilica content. Meanwhile, the trend of strain at fracture (%) or elongation has decreased significantly with the addition of NS, indicating an increase in brittleness. As nanosilica content increases, the material's stiffness (E) improves, making the composite stronger and more resistant to deformation. However, this increase in stiffness comes at the cost of reduced ductility, as shown by the decreasing strain (%) values. At 7 wt.% nanosilica, the composite exhibits the highest stiffness but the lowest strain (%), indicating that it becomes stiffer but more brittle.

The data indicate that the inclusion of 5 wt.% nanosilica results in maximum improvements in tensile strength and modulus, although this enhancement is accompanied by challenges in processing due to increased viscosity

and potential agglomeration. While the use of 7 wt.% nanosilica yields the highest ultimate tensile strength, and the overall stiffness is reduced, likely due to processing difficulties and particle agglomeration. Consequently, for further applications, this research recommends utilising a 5 wt.% nanosilica (5NSW) concentration to achieve an optimal balance of mechanical performance and processability. The tensile properties of Willkat resin improve in terms of strength with the addition of NS, but the material becomes more brittle, as indicated by the reduced strain at fracture. The addition of an optimal weight ratio of nanosilica powder enhances the strength and modulus properties of the composite while maintaining its ductility [16].

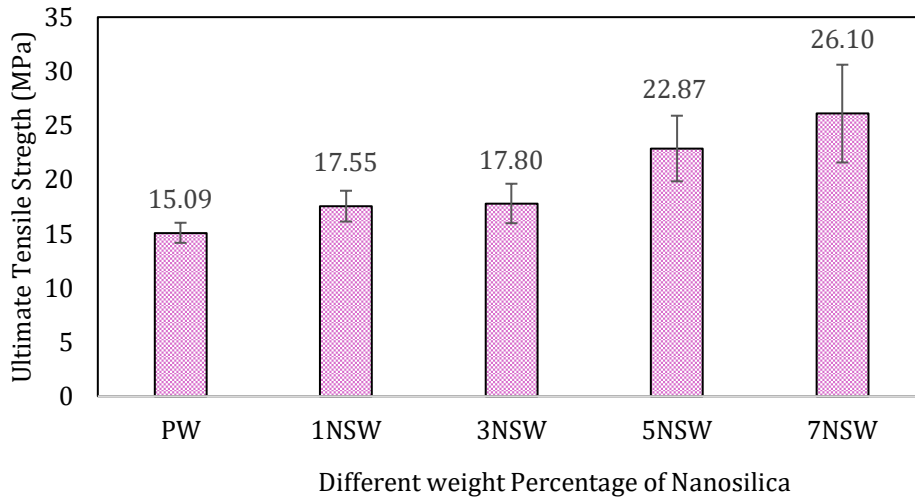


Fig. 1 Ultimate Tensile strength of different weight percentages of nanosilica filler in polymer

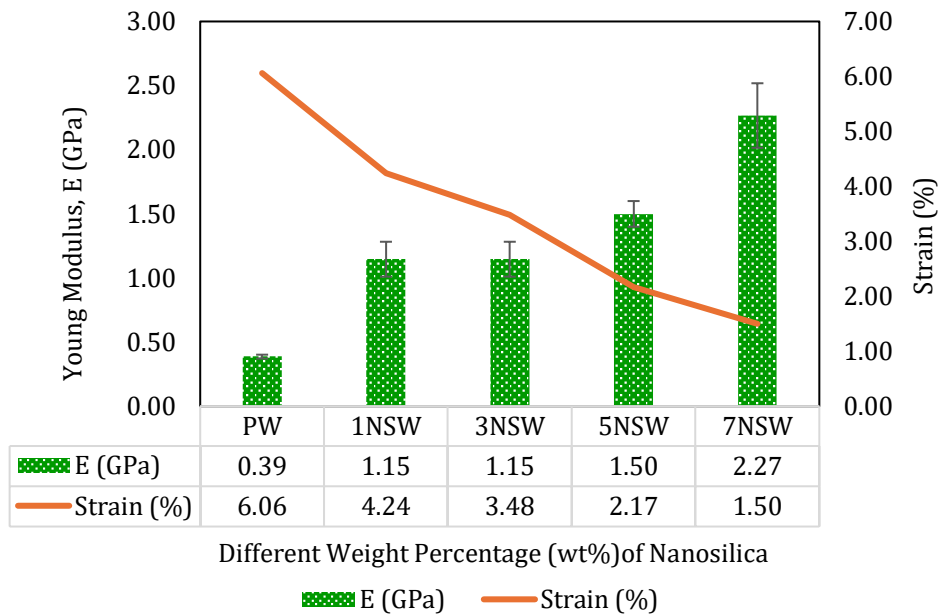


Fig. 2 Young Modulus and Elongation of different weight percentages of nanosilica filler in polymer

5.2 Volume Fraction of FRP Composite

Table 1 presents the value of fibre volume fraction (%) in FRP composites obtained using burn-off and acid digestion methods. A higher volume fraction of fibres generally increases the tensile strength of the composite. This enhancement occurs because fibres possess greater tensile strength than the matrix material, and as their proportion increases, so does the composite's load-bearing capacity. Additionally, a higher fibre-to-resin ratio contributes to a stronger fibre-matrix interface bonding, further improving the composite's ability to withstand high tensile forces. Studies indicate that optimising the fibre volume fraction can significantly enhance the tensile strength of the composite [17], [18]. Results show that the B/B commingle fibres give better results compared to others, with a lower percentage of voids.

5.3 The Ultimate Tensile Strength of Pure and Nano Silica Willkat Resin with Different Fibre Combinations and Orientations

Fig. 3 shows a comparison of the ultimate tensile strength (UTS) of composite materials using PW resin and 5NSW resin with different fibre combinations oriented at both 0° and 90°. The results indicate significant variations in tensile strength based on the type of resin (PW and 5NSW powder), fibre combination, and fibre orientation at 0° and 90°. The study discusses materials that combine synthetic glass fibre with natural fibres such as Arenga Pinnata and basalt. For the B/B configuration, the ultimate tensile strength (UTS) results in the 0° orientation are 185.79 MPa for PW and 302.55 MPa when 5NSW is added. In the 90° orientation, PW has a UTS of 6.17 MPa, while with 5NSW, the results are 8.14 MPa. The UTS is substantially higher in the 0° orientation compared to the 90° orientation for both PW and 5NSW resins. The inclusion of nanosilica improves the tensile strength by 62.81% in the 0° orientation and by 31.89% in the 90° orientation. The significant difference between the 0° and 90° orientations can be attributed to the anisotropic nature of composite materials, where fibres aligned along the load direction (0°) contribute more to the tensile strength than fibres oriented perpendicularly (90°).

Table 1 Volume fraction and voids content in FRP composites

Sample	PW			5NSW		
	Fibre Volume Fraction (%)	Matrix Volume Fraction (%)	Void (%)	Fibre Volume Fraction (%)	Matrix Volume Fraction (%)	Void (%)
B/B	56.14	39.59	4.27	57.53	38.02	4.45
G/G	54.21	41.02	4.77	59.20	35.60	5.20
AP/B	55.87	39.47	4.66	47.74	47.71	4.55
AP/G	61.88	33.69	4.43	50.04	44.61	5.35
AP/AP	56.14	39.59	5.08	49.75	45.14	5.11

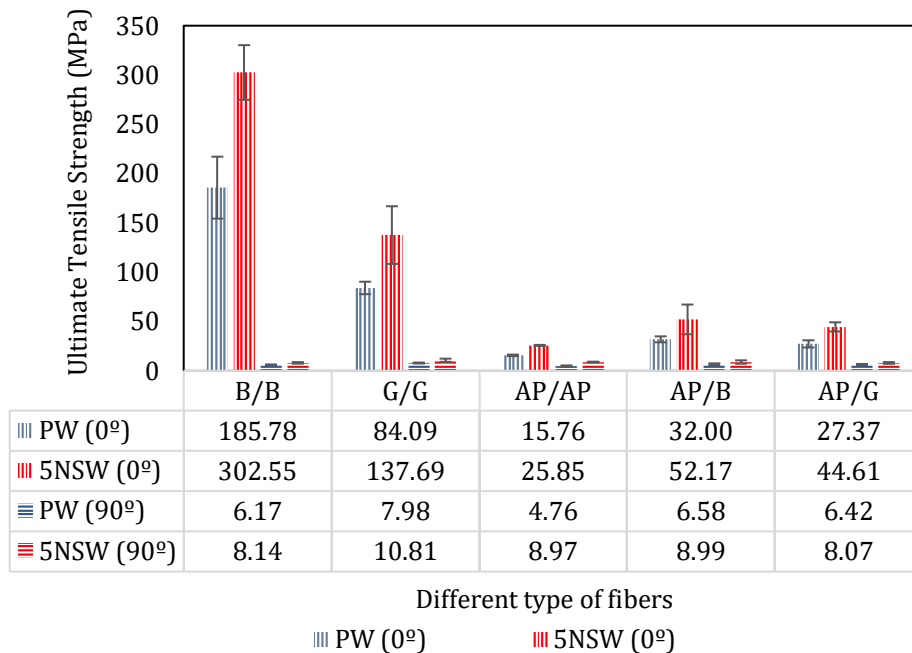


Fig. 3 The effect of nanosilica on tensile strength of Willkat resin with different fibre combinations and fibre orientations

For the G/G configuration in the 0° orientation, the results show that PW has an ultimate tensile strength (UTS) of 84.10 MPa, while 5NSW has a UTS of 137.69 MPa. In the 90° orientation, PW has a UTS of 7.98 MPa, and 5NSW has a UTS of 10.81 MPa. Like the basalt fibres, the glass fibre composites exhibit significantly higher UTS in the 0° orientation. The improvement with nanosilica is 63.77% in the 0° orientation and 35.45% in the 90° orientation. This indicates that the addition of nanosilica effectively enhances the matrix, improving the fibre-matrix interface strength, which is more critical in the 0° orientation where the load is directly applied along the fibres. For the AP/AP configuration in the 0° orientation, PW has an ultimate tensile strength (UTS) of 15.76 MPa,

Fig. 4 shows the FRP composite results from the tensile test for a sample with a 0° fibre orientation. The sample demonstrates severe delamination and fibre pull-out. The damage is extensive, with significant matrix cracking and fibre failure. The results demonstrate that the addition of nanosilica to the Willkat resin significantly enhances the ultimate tensile strength (UTS) across all fibre configurations and orientations. The enhancement is more pronounced in the 0° orientation, where fibres are aligned with the load direction, but substantial improvements are also observed in the 90° orientation. This indicates the effectiveness of nanosilica in enhancing the interfacial bonding between the fibres and the matrix, resulting in improved load transfer and overall composite strength [19].

Fig. 5 shows the SEM image of different fibres. The pull-out of the fibre and micro-void of the composite shows the interaction between them [20]. The image of B/B and G/G fibre shows elongated, cylindrical structures that are densely packed. This structure suggests a high degree of alignment and packing density, which can contribute to the material's strength and rigidity in PW resin. For 5NSW, the image shows similar cylindrical structures, but they are embedded in a matrix with nanosilica particles. The inclusion of nanosilica can enhance the material's mechanical properties, such as stiffness and resistance to deformation, due to the reinforcing effect of the nanoparticles [21].

For AP/AP, the SEM shows that the fibre is irregular and less dense, indicating heterogeneous material with varied fibre orientations. The addition of nanosilica results in a more homogeneous structure with better-defined edges. The hybrid of AP/G and AP/B structures shows the coiled and tangled combination of elongated fibres. It could provide a balance between strength and flexibility between natural and synthetic fibres [22].

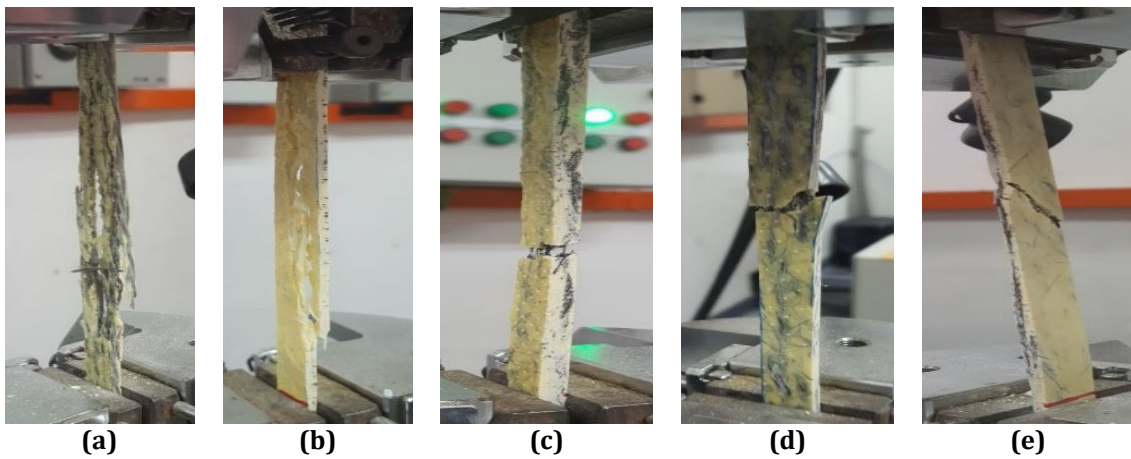


Fig. 4 The tensile test sample in 0-degree direction – (a) B/B; (b) G/G; (c) AP/AP; (d) AP/B; and (e) AP/G

Sample	Pure Willkat	Nanosilica Willkat
B/B		
G/G		

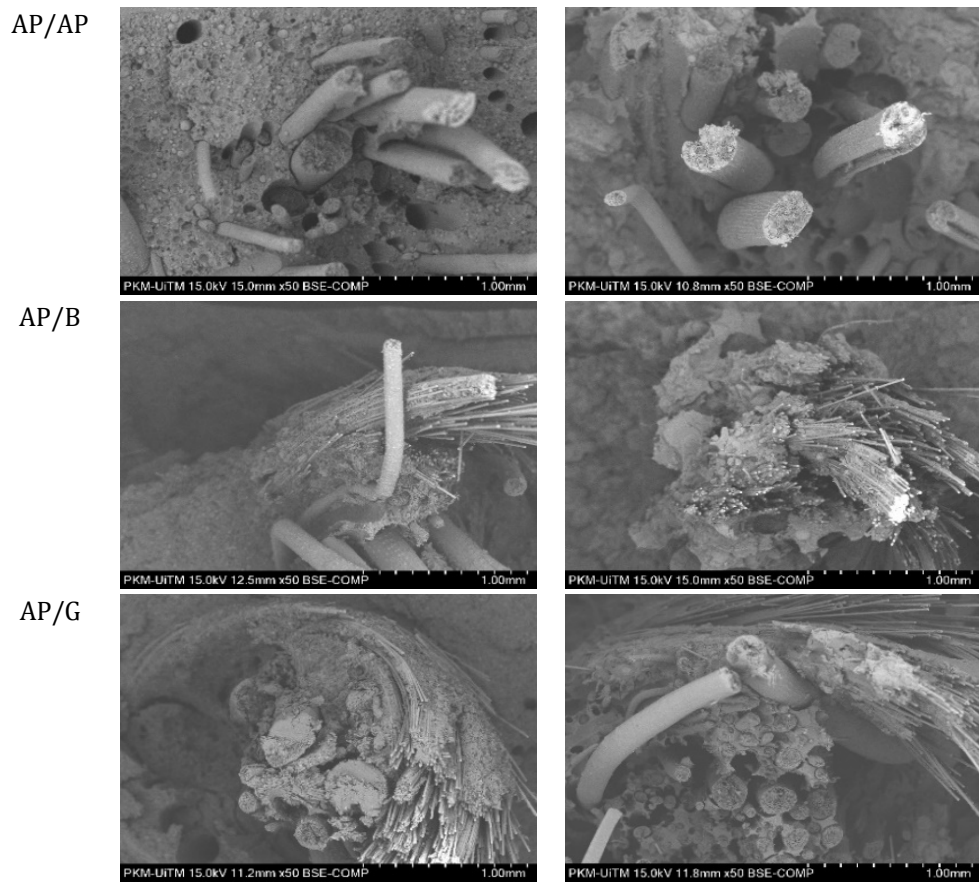


Fig. 5 The scanning electron microscope (SEM) images provided illustrate the microstructures of various samples labelled as B/B, G/G, AP/AP, AP/B, and AP/G

6. Conclusions

The addition of nanofillers in the development of resin can enhance the mechanical properties of composites. Specifically, using nanosilica as a nanofiller improves the tensile, compressive, and flexural strength of the composite material. Their small size allows them to fill the gaps between larger particles, resulting in a denser and stronger material. Additionally, the inclusion of nanosilica enhances the toughness of the composite, making it more resistant to crack propagation and improving its overall durability. Nanosilica particles also contribute to an increased modulus of elasticity, enabling the material to better withstand deformation under load. Furthermore, nanosilica enhances the load transfer efficiency between the matrix and the reinforcing fibres, leading to improved strength and performance of the composite. By aiding in the even distribution of stress throughout the material, nanosilica reduces the likelihood of failure at stress concentration points. These factors underscore the importance and relevance of research into poly silicate isocyanate (Willkat) reinforced with nanosilica, as it promises to deliver high-performance materials suited to a wide range of applications while addressing critical environmental and durability challenges. The addition of nanosilica powder yields better results in the case of commingled fibre, achieving the highest ultimate strength, particularly with B/B comingle, when nanosilica powder is added.

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Conflict of Interest

There is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: **Writing, conceptualisation, design, data collection, analysis, and interpretation of results:** Jamaliah Md Said; **Supervision, Review, and editing:** Aidah Jumahat; **Review and editing:** Jamaluddin Mahmud.

References

- [1] Cosmoiu, I., Apostol, D. A., Picu, C. R., Constantinescu, D. M., Sandu, M., & Soroohan, S. (2016). Influence of filler dispersion on the mechanical properties of nanocomposites. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2016.03.027>
- [2] Turaka, S., & Bandaru, A. K. (2023). Enhancement in mechanical properties of glass/epoxy composites by a hybrid combination of multi-walled carbon nanotubes and graphene nanoparticles. *Polymers*. <https://doi.org/10.3390/polym15051189>
- [3] Shaker, K., Adnan, M., Nawab, Y., Umair, M., Jabbar, M., Siddique, A., & Ahmad, A. (2023). Mechanical performance of glass/epoxy composites loaded with silane-treated aluminum hydroxide fillers. *Polymers*. <https://doi.org/10.3390/polym15173514>
- [4] Nassar, A., & Nassar, E. (2013). Study on mechanical properties of epoxy polymer reinforced with NanoSiC particles. *Nanoscience and Nanoengineering*. <https://doi.org/10.13189/nn.2013.010201>
- [5] Ding, J., Qin, Z., Luo, H., Yang, W., Wang, Y., & Huang, Z. (2020). Nano-silica modified phenolic resin film: Manufacturing and properties. *Nanotechnology Reviews*. <https://doi.org/10.1515/ntrev-2020-0018>
- [6] Chandrasekar, M., Ishak, M. R., Sapuan, S. M., Leman, Z., & Jawaid, M. (2017). A review on the characterisation of natural fibres and their composites after alkali treatment and water absorption. *Plastics, Rubber and Composites*. <https://doi.org/10.1080/14658011.2017.1298550>
- [7] Nayana, V., & Kandasubramanian, B. (2020). Advanced polymeric composites via commingling for critical engineering applications. *Polymer Testing*. <https://doi.org/10.1016/j.polymertesting.2020.106774>
- [8] Awais, H., Nawab, Y., Amjad, A., Anjang, A., Akil, H. M., & Abidin, M. S. Z. (2019). Effect of comingling techniques on mechanical properties of natural fibre reinforced cross-ply thermoplastic composites. *Composites Part B: Engineering*. <https://doi.org/10.1016/j.compositesb.2019.107279>
- [9] Nayana, V., & Kandasubramanian, B. (2020). Advanced polymeric composites via commingling for critical engineering applications. *Polymer Testing*. <https://doi.org/10.1016/j.polymertesting.2020.106774>
- [10] Imraan, M., Ilyas, R. A., Norfarhana, A. S., Bangar, S. P., Knight, V. F., & Norrrahim, M. N. F. (2023). Sugar palm (*Arenga pinnata*) fibers: New emerging natural fibre and its relevant properties, treatments and potential applications. *Journal of Materials Research and Technology*. <https://doi.org/10.1016/j.jmrt.2023.04.056>
- [11] Sherwani, S. F. K., Zainudin, E. S., Sapuan, S. M., Leman, Z., & Abdan, K. (2021). Mechanical properties of sugar palm (*Arenga pinnata* Wurmb. Merr)/glass fiber-reinforced poly (lactic acid) hybrid composites for potential use in motorcycle components. *Polymers*. <https://doi.org/10.3390/polym13183061>
- [12] ASTM D638-14 (2014). Standard Test Method for Tensile Properties of Plastics. <https://doi.org/10.1520/D0638-14>
- [13] ASTM D3039M-17 (2017). Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. https://doi.org/10.1520/D3039_D3039M-17
- [14] ASTM D317-11 (2015). Standard Test Methods for Constituent Content of Composite Materials. <https://doi.org/10.1520/D3171-11>
- [15] Sprenger, S. (2020). Nanosilica-toughened epoxy resins. *Polymers*. <https://doi.org/10.3390/polym12081777>
- [16] Ogradowska, K., & Urbański, M. (2023). Nanosilica modification of epoxy matrix in hybrid basalt-carbon FRP bars—impact on microstructure and mechanical properties. *Materials*. <https://doi.org/10.3390/ma16051912>
- [17] Fu, S., Sun, Z., Huang, P., Li, Y., & Hu, N. (2019). Some basic aspects of polymer nanocomposites: A critical review. *Nano Materials Science*. <https://doi.org/10.1016/j.nanoms.2019.02.006>
- [18] Abdullah, A. H., Amri, A. F., Mohd Salleh, F., Abdul Halim, N. H., & Tharazi, I. (2021). Effect of fibre weight fraction on the flexural and dynamic mechanical properties of arenga pinnata fibre and its hybrid composites. *Scientific Research Journal*. <https://doi.org/10.24191/srj.v18i1.11385>

- [19] Abdel-Rahim, R. H., Attallah, M. S., & Mohammed, R. A. (2022). Investigation the effect of nano silica dioxide additives on the properties of epoxy resin for using in industrial applications. *Materials Science Forum*, 1050, 103-113.
- [20] Muralidhara, B., Babu, S. K., & Suresha, B. (2020). Utilizing vacuum bagging process to prepare carbon fiber/epoxy composites with improved mechanical properties. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2019.09.051>
- [21] Sapiai, N., Jumahat, A., Jawaid, M., Midani, M., & Khan, A. (2020). Tensile and flexural properties of silica nanoparticles modified unidirectional kenaf and hybrid glass/kenaf epoxy composites. *Polymers*. <https://doi.org/10.3390/polym12112733>
- [22] Vazic, B., Abali, B. E., Yang, H., & Newell, P. (2022). Mechanical analysis of heterogeneous materials with higher-order parameters. *Engineering with Computers*. <https://doi.org/10.1007/s00366-021-01555-9>