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Research Article

Influence of Nano-/Microfiller Addition on Mechanical and Morphological Performance of Kenaf/Glass Fibre-Reinforced Hybrid Composites

L. Karthick,[1] R. Rathinam,[2] Sd. Abdul Kalam,[3] Ganesh Babu Loganathan,[4] R. S. Sabeenian,[5] S. K. Joshi,[6] L. Ramesh,[7] H. Mohammed Ali,[8] and Wubishet Degife Mammo[9]

[1]*Department of Mechanical Engineering, Hindusthan College of Engineering and Technology, Coimbatore, 641032 Tamil Nadu, India*
[2]*Department of Chemistry, Sri Eshwar College of Engineering, Coimbatore, 641202 Tamil Nadu, India*
[3]*Department of Mechanical Engineering, PVP Siddhartha Institute of Technology, Vijayawada, Andhra Pradesh 520007, India*
[4]*Department of Mechatronics, Faculty of Engineering, Tishk International University-Erbil, Kurdistan Region, Iraq*
[5]*Department of Electronics and Communication Engineering, Sona College of Technology, Salem, Tamil Nadu 636005, India*
[6]*Department of Physics, University of Petroleum and Energy Studies, Dehradun 248007, India*
[7]*Department of Electronics and Communication Engineering, M. Kumarasamy College of Engineering, Karur, 639113 Tamil Nadu, India*
[8]*Department of Mechanical Engineering, SRM Institute of Science and Technology-Ramapuram Campus, Chennai, 89 Tamil Nadu, India*
[9]*Department of Mechanical Engineering, Wollo University, Kombolcha Institute of Technology, Kombolcha, South Wollo, 208 Amhara, Ethiopia*

Correspondence should be addressed to L. Karthick; bemechkarthick@gmail.com
and Wubishet Degife Mammo; wubishetdegife7@gmail.com

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Natural-based composite's progress as carriers has revealed many benefits in biomedicine, notably in the construction field, synthetic biology, and genetic engineering. Compared to analogous composites without nanoparticles, incorporating nanoparticles into polymeric materials improved architectural performance, physiological connections, and ecological features. The major goal of the current investigation is to determine the impact of nano-/micro-TiO_2 on the mechanical characteristics of kenaf/glass/epoxy hybrids. The samples have been created using a hand layup method and a variety of filler loading and stacking sequences. The addition of nano-/microfiller significantly improved the mechanical performance of the epoxy/hybrid composite material. It was discovered that nanofiller-added composite materials fared better when composites were compared to and without microfilter-added composites. SEM was used to investigate the microstructure of the interfaces to ensure a good understanding of interfacial adherence between the reinforcement and their matrix. Compared to pure epoxy resin, the 15 wt% of microfiller additions of glass-kenaf-kenaf-glass type composites exhibit a 39.48% improvement in tensile and a 42.88% improvement in flexural. Similarly, 5 wt% nanofiller addition reveals a 44.214% improvement in tensile and a 50.50% improvement in flexural.

1. Introduction

From antiquity to the present, scientists have been looking for novel natural fibres to replace artificial fibres in the polymeric sector. The researchers used organic fibres like cotton, wood, jute, and coco fibre as they are cost-effective and lightweight. These organic resources have a lot of rigidity and high modulus [1]. Natural fibre composites have much poorer mechanical and physical qualities than artificial fibre. There is an increasing need for environmentally friendly materials and a desire to reduce the cost of common polymeric fibres. Several researchers are currently focusing on natural fibre composites, and natural or synthetic adhesives linked to organic textiles [2, 3]. Fibre-reinforced polymeric materials have been extensively used in various sectors owing to their low strength and high durability. A fibre-based composite is made up of two components: fibre and matrix. Fibres can be artificial, and then, they can be sourced from natural resources like forests. Synthetic fibre-reinforced composites outperform natural fibre-reinforced composites in terms of their physical properties [4]. It reduces low mechanical properties, low corrosion resistance, and low durability of natural fibre composites. It may be eliminated by the chemical modification of fibres converted into less hydrophilic. The chemical modification of the fibres formed covalent bonds between the fibres and matrix. That natural fibre composite materials are hydrophilic, which is why they tend to absorb moisture. The woven glass mat layer was placed as the outer cover on each side of the jute-hemp hybrid laminate to protect composite materials based on natural fibres from this drawback. Unfortunately, the nondegradability of synthetic fibres leads to dumping, reprocessing, and environmental consequences, resulting in significant environmental pollution, which is a concern for governments and researchers. As a result, synthetic materials must be substituted in part or totally by natural textiles, depending on the functional and durability requirements of fibre-based composites [5, 6]. Natural fibres such as jute, cotton, bananas, sisal, hemp, flax, kenaf, and pineapple sheathing are being investigated as viable and appealing alternatives to synthetic fibres in several uses, including autos, construction, and a variety of consumer profit-making tactics. Natural fibres have a number of advantages, including low density, high biocompatibility, cheap cost, nonabrasiveness, and nontoxicity, making them ideal for filler or reinforcement in polymeric composites [7–9]. Among several natural fibre groups, the current development in the physical qualities of kenaf fibre composites and polymeric materials is believed to be exceptional.

Bast fibre bunches from shorter kenaf are frequently used to make ropes, rugs, carpets, sheets, and other items (Hibiscus cannabinus L., Malvaceae). Tree fibres such as cotton, hemp, and Kapok had lower tension behaviour, creating them idyllic for both strength and lightweight applications. Despite the rising popularity of these combinations, present value still impacts fibre choice beyond quality materials [10–12]. Natural fibres such as cotton, jute, hemp, and sisal are renewable resources; even these natural fibres' agricultural waste is used to make composites. The selection of natural fibre for making composite considers the following criteria: thickness, L/D proportion, heat resistance, obtainability of organic filaments, cost of the fibre, and other mechanical properties.

As a result, the researchers blended several kinds of fibres into the polymeric matrices to create a hybridized composite which may dramatically enhance the polymeric composite's capabilities. A hybrid composite is a material of two or more reinforcing fibres arranged in a certain shape and scale best to serve a given technical function [13]. Kevlar/carbon and carbon/glass-based polymeric materials are the most prevalent hybridized composites in today's engineering industry, providing higher strength and shock resistance to the polymer matrices [14]. Composites comprising two fibres in the same matrix are hybrid composites. Hybridization can improve the material properties of combinations by addressing the defects of distinct composites. Velmurugan and Babu and Swamy Nadh investigated a glass/epoxy hybrid composite material using natural fillers. They discovered that a coco filler-based hybrid composite had superior mechanical capabilities to another filler-based epoxy composite [15, 16]. Sumesh et al. [17] studied the physical modulus, impact, and moisture content of untreated fibre hybrid polyester composites mathematically and experimentally. They discovered that the mechanical and physical properties are intermediate among kenaf/glass fibre materials. According to these findings, studies have explored the mechanical performance of the proposed fibre composites incorporating multiple organic additives with polymer matrices to improve features that may defeat synthetic fibre in many uses. When loading is not a primary need, the natural fibre hybrid composite is often effective in minimizing the use of artificial fabric to some amount [18]. In polymeric materials, research is ongoing to produce new nanosized materials and build nanomaterials. Mechanical qualities will be much enhanced due to the integration of these little ceramic fillers. In the field of innovation, utilizing additive material at the micro- and nanoscale with composite samples is a fascinating use. The use of nanofillers to compensate for the lack of adhesion between the matrix and the fibre is the current trend in improving biomaterials' physical and mechanical properties. Thanks to an improved matrix and additives with homogeneous nanoparticle dispersion, enhanced mechanical properties were achieved. Organic and inorganic nanofillers are the two nanomaterials [19, 20].

Most studies employed synthetic fillers such as aluminium powder, silicate minerals, and silicon dioxide. Coconut fibre nanoparticles, cellulose nanofiller, carbon black, and other organic nanofillers can be utilized instead. Nanocomposite films enhance the interfacial contact between the matrix and the fibre [21]. Using nanofillers provides a consistently distributed difficulty since nanoparticles want to form groups in the matrix. The water content of a hybrid composite made of natural fibres and nanoparticle fillers is reduced, while mechanical properties are improved. Vlasveld et al. [22] produced a composite with nanosilica strengthened by fibreglass in a polypropylene matrix and then studied the adhesion properties between fibres and matrix and the mechanical characteristics of the polymeric matrix, like rigidity and yielding behaviour. The dynamic vibrating and damping properties of hybrid nanovinyl ester composites were investigated by Chandradass et al. [23]. E-glass fibre, diced standing mat, and nanoscale mud were used to make this composite. The inner dampening impact of composite samples was greatly improved due to nanofillers' distribution in the matrices and E-glass fibre. Meguid and Sun [24] used two separate homogeneously distributed nanoparticles, carbon nanotubes and aluminium nanoparticles, to make hybrid reinforcement.

The findings demonstrated that the proportion of nanomaterials by weight significantly influenced the interface's strength. Few studies have looked at the mechanical characteristics of micro-/nanofiller organic biocomposites. A survey of the present evidence indicates that, despite the many benefits of organic composite samples, there has been little research into ceramic nanoreinforcements in organic and traditional fibre hybrid composites. Throughout this work, an initiative has been taken to produce TiO_2/kenaf/glass epoxy composites using ceramic (nano/micro) fillers and explore the influence of filler addition on engineering properties.

2. Experimental Works

2.1. Resources. As a reinforcing material, two kinds of bidirectional fibres were selected. The first material utilized in hybrid composite processing is kenaf, a naturally renewable resource. Another fabric form is classic glass fibre, a synthetic and commercially produced material. TiO_2 is a filler substance utilized as a micro- and nanoscale strengthening filler element. The sizes of the micro- and nanofiller TiO_2 are 10–50 μm and 100–40 nm, correspondingly. Both the reinforcing materials were procured from Rithu Fiber Industry, Vellore, Tamil Nadu, India. The TiO_2 filler particles and epoxy matrix were provided by Naga Chemicals, Chennai, Tamil Nadu, India. Figure 1 shows the photographic images of Reinforcement and filler materials.

2.2. Composite Preparations. A hand layup process was used to create a hybrid laminated composite comprising three layers of woven kenaf and glass in a bidirectional configuration. The common reinforcing phases in all composites include kenaf fibre and glass fibre. TiO_2 is used as a filler at the micro- and nanoscales. The parameters of fibre and matrix in hybrid composites are revealed in Table 1. The nanocomposites were prepared using a stainless-steel mould with $150 \times 150 \times 3$ mm dimensions. The matrix substance is epoxy resin. The curing agent is combined with the resin at the specified weight proportion. Two separate sets of composites were created. Even before kenaf/glass fibre is strengthened in the matrices, the micro-TiO_2 (10, 15, and 20 wt%) is employed as a filler and combined with the epoxy matrix in the first batch.

Similarly, nano-TiO_2 (2.5, 5, and 7.5 wt%) is employed as a filler material and combined with the epoxy resin. The matrix weight percentage fluctuates depending on the presence of micro-/nanofillers. A mould release paper is retained on the bottom and top of the stainless-steel mould for rapid and simple release of the composite structure. The mould-releasing bouquet is also sprayed to the inside edge of the mould walls to make exclusion of the composites easier. A mechanical swirling procedure is used for 10 minutes before fibre inclusion to ensure the appropriate distribution of the TiO_2 fillers in the matrices. The surplus polymer is carefully monitored to ensure it does not leak out of the mould. Before being retrieved from the mould, every composite is dried for 24 hours at room temperature under a weight of around 20 kg. Figure 2 shows the hand layup composite lamination process.

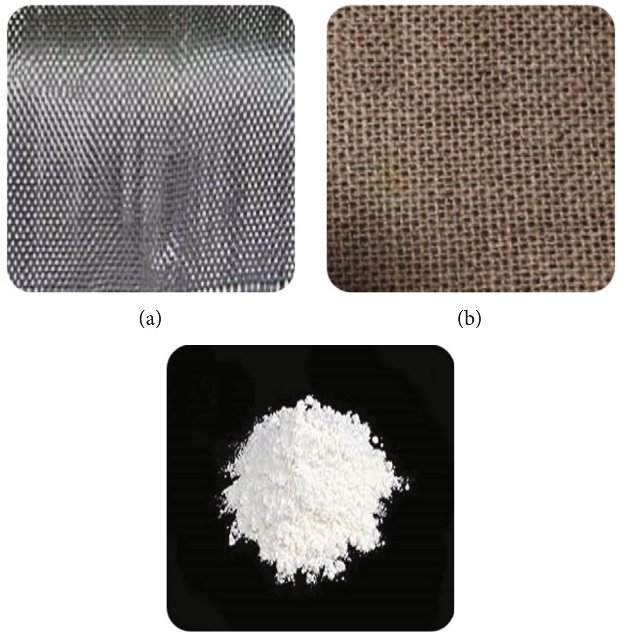
2.3. Composite Characterization. Normally, flattened samples are used for tensile testing. An ordinary trial procedure is employed according to ASTM D 638-3. The examination sample is 150 mm long. The ASTM D 790 standard conducted the flexural tests. 125 mm long and 10 mm width samples were sliced and encumbered using bending with a 16 : 1 suggested span-to-depth. A scanning electron microscope is used to analyze the eroded surface of the tested laminates. Gold glue is used to adhere the specimens to the stub. A small layer of platinum is vacuum dried to progress the conductance of the degraded specimens.

3. Result and Discussion

3.1. Tensile Behaviour of Nanocomposites. Figure 3 illustrates the influence of TiO_2 microfiller inclusion in hybrids and clean kenaf composites. Microfillers in varying weight proportions (10, 15, and 20%) are incorporated into a polymer composite and evaluated for tension characteristics according to ASTM D 638-3 ($150 \times 20 \times 3$) specifications. Clean fibreglass, kenaf composite materials, and plain epoxy are made and evaluated for comparisons of filler particles and hybridized impact. In both hybrids and plain kenaf composites, the strength of the composite materials is markedly increased by the inclusion of fillers. As the filler content rises to 15 wt%, so does the strength, which begins to decline [25]. It might be due to a discontinuity as in delamination resulting from particles' readmission to a polymer. The particles could no longer carry significant stress due to this (delamination), and the composite strength declines as nanoparticle content increases. After hybridized and filler additions, all composites can match the toughness of fibreglass. Composite glasses as outermost layer combinations with 15% TiO_2 filler addition outperform pure traditional composite materials in terms of tensile performance.

The impact of nanoparticle inclusion in hybrids and basic kenaf compositions is shown in Figure 4. Various weight proportions (2.5, 5, and 7.5 wt%) are incorporated into hybrids and native kenaf composites, and the tensile characteristics are assessed according to ASTM specifications. In hybrid composites and kenaf composites, the impact of filler addition is readily visible. The strength of all composites rises even as filler application increases up to 5 wt% and then begins to degrade above 5 wt%. Compared to plain glass fibre, the combination of G-K-K-G with 5 and 7.5 wt% nano-TiO_2 filler provides 5 and 2% more strength [8].

Figures 5 shows the effect of nanosized and microfiller inclusions in composite materials. Because of the mismatch in fibre, filler, and polymer ratios, the outcome improved up to 15 wt% with the inclusion of microfiller and decreased after that. Likewise, in nanofiller composite samples, the highest strength is seen at 5 wt% filler and begins to decrease at 7.5 wt%. When comparing the strength of 2.5 wt% nanofiller to the impact of micro- and nanofiller in composite samples,



(a) (b) (c)

Figure 1: Photographic images of (a) glass fibre, (b) kenaf fibre, and (c) TiO_2 filler.

Table 1: Experimental parameters and their combinations.

Symbol number	Stacking sequence	Reinforcement content (wt%)		Fibre concentration (wt%)	Epoxy resin content (wt%)
		Kenaf	Glass		
A	Pure epoxy	0	0	0	100
B	G-K-G-K	50	50	22	78
C	K-G-G-K	50	50	22	78
D	G-K-K-G	50	50	22	78

the strength of 2.5 wt% nanocomposite is high compared to 15 wt% fill in all composite materials. It demonstrates that when the filler size decreases, the possibility of improving the composites' toughness and responsiveness grows [26, 27]. The G-K-K-G 5 wt% nanofiller nanocomposite has the highest tensile strength.

Fibre-reinforced plastic composites (FRPC) had to undergo machining operations such as drilling, grooving, and surface finishing to build up structural components of automobiles, aeroplanes, etc. In machining operations, drilling is most commonly used to join structural elements. Failure of FRPC components is reported due to tool wear mechanisms, type of fibre, resin, the orientation of the fibre and number of layers, etc. Therefore, analysis/optimizing associated machining parameters are vital to avoid damages and failures in FRPC due to faults emerging from machining operations.

3.2. Bending Behaviour of Nanocomposites. The impact of TiO_2 microfilters on hybrid and unadulterated kenaf composites is shown in Figure 6. The blends are given various weight proportions (10, 15, and 20%) and evaluated for bending characteristics according to ASTM D790 ($125 \times 10 \times 3$) specifications. A glass fibre, a kenaf fibre, and a tidy epoxy composite are also being evaluated for comparison. However, no composites overcome the toughness of the fibreglass after recombination and filler inclusion, as seen in figure 5. The strength of kenaf fibre composites constantly rises with the inclusion of TiO_2 filler, which might be due to adherence to strong fibre-- filler matrices. The polymer and filler in a fibre composite are responsible for transferring load to rigid fibres via shear forces at the junction. It necessitates a strong connection between matrices, the fillers, and the fibres. Because the toughness of kenaf composite improves with the inclusion of filler, the interfacial interaction between kenaf-TiO_2 and the matrix is stronger. The strength of hybrid composites improves until 15 wt% filler is added, after which it declines [28, 29]. G-K-G-K composites with a 15 wt% TiO_2 filler addition outperform pure traditional fibre composites in comparison.

The impact of nanoparticle inclusion in hybrids and unadulterated kenaf composites is shown in Figure 7. Nanoparticles in varying weight proportions (2.5, 5, and 7.5 wt%) were introduced to hybridization and clean kenaf composites

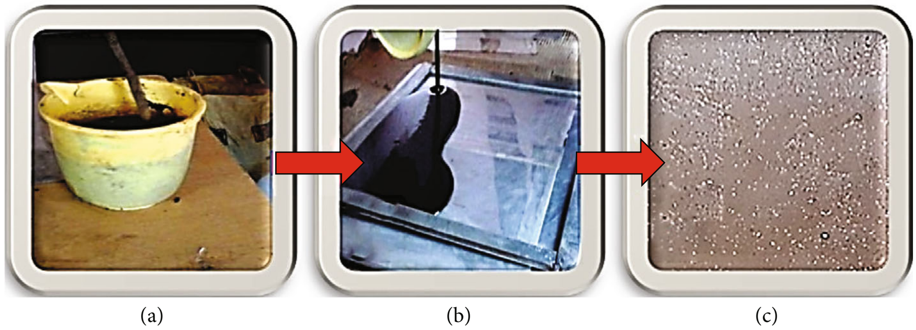


FIGURE 2: Composite preparations through hand layup process. (a) Manual stirring of nanoparticle. (b) Lamination process. (c) Composite plate.

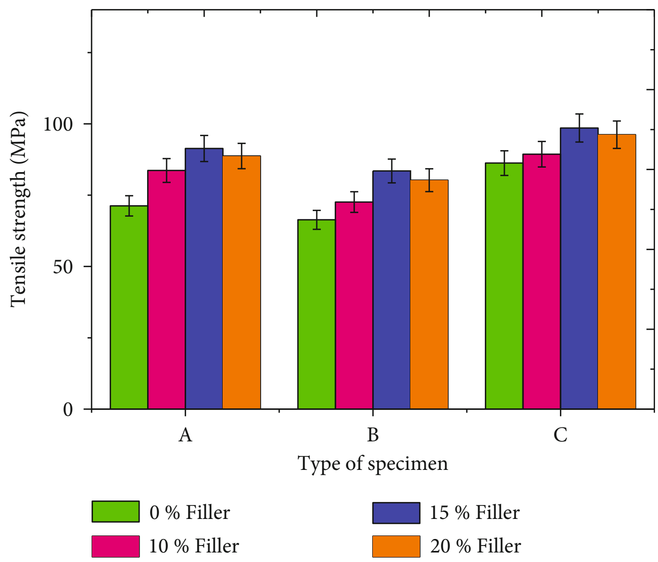


FIGURE 3: Tensile strength of kenaf/glass/epoxy/microfiller-based hybrid composite.

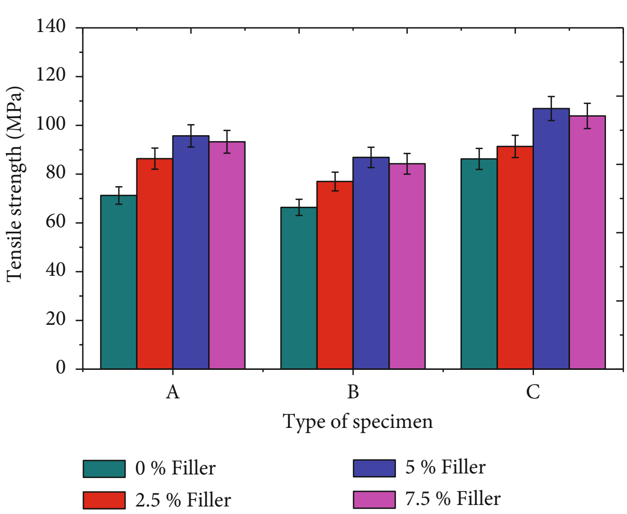


FIGURE 4: Tensile strength of kenaf/glass/epoxy/nanofiller-based hybrid composite.

and evaluated for bending characteristics according to ASTM D790 standards. The strength of hybridized and kenaf materials rises as the nano-TiO_2 inclusion rises to 5% by weight. It has also been discovered that G-K-G-K with 2.5 and 5 wt% nanoparticle additions has 5 and 10% stronger properties than glass fibre. The nanofiller has the potential to improve fracture resistance. The decrease in composite flexural strength as filler concentration increases is likely due to particle incompatibilities with the epoxy, resulting in poor system interfacing. Fibre-fibre contact, vacancies, and dispersion issues might blame for the reduced bending characteristics [30, 31].

With the help of natural and synthetic fibres, the enlargement was done by polymer-based, fibre-reinforced composites to gain in both fibre-reinforced composites. The natural FRPC had some demerits like low oxidization resistance and hydrophilic nature. To overcome the above demerits, the following suggestion was encrypted. For the improvement of tribological and mechanical properties, the synthetic fibres and the natural fibres were combined to form hybrid composites. To develop the hybrid composites, synthetic fibre and natural fibre were incorporated into the matrix.

The impacts of adding micro- and nano-TiO_2 fillers to hybrid composites are depicted in Figure 8. The impact of

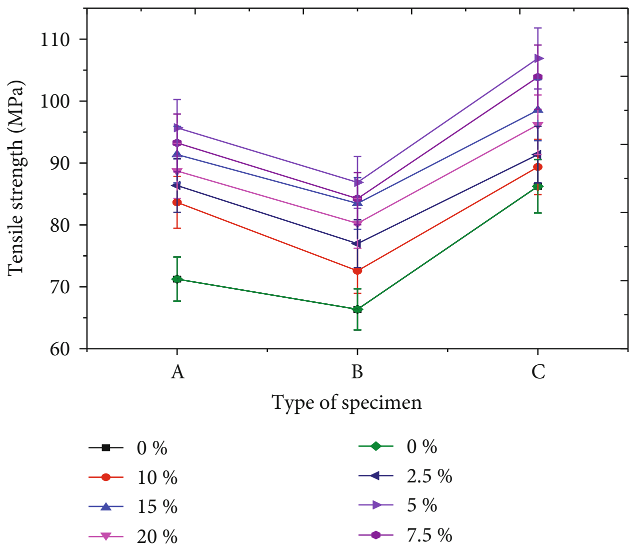


Figure 5: Comparison of tensile strength of microfiller (0 to 20%) and nanofiller (0 to 7.5%) incorporations of hybrid composites.

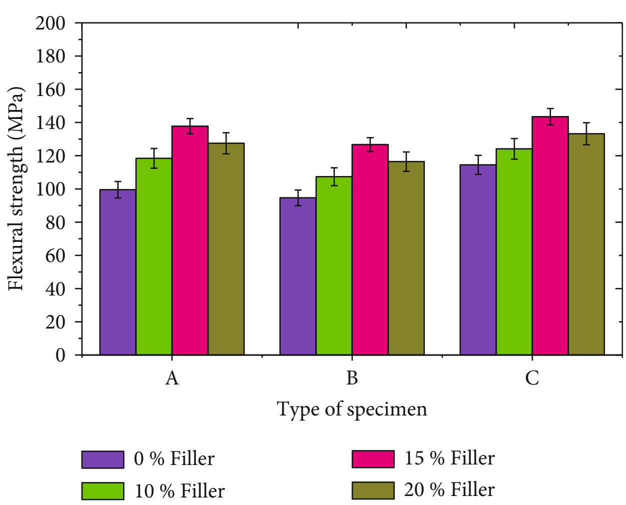


Figure 6: Flexural strength of kenaf/glass/epoxy/microfiller-based hybrid composite.

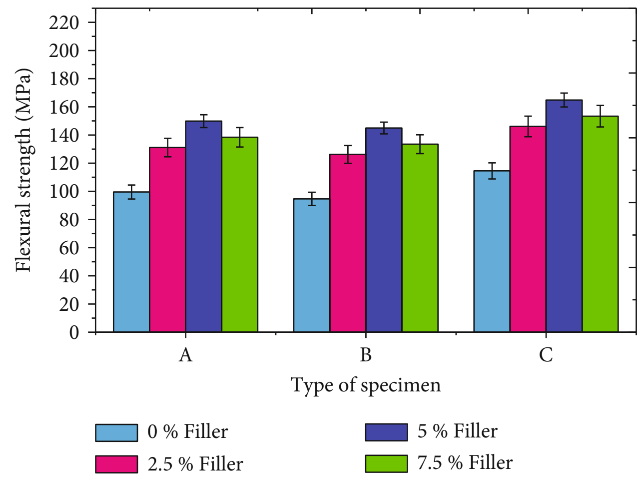


Figure 7: Bending behaviour of kenaf/glass/epoxy/nanofiller-based hybrid composite.

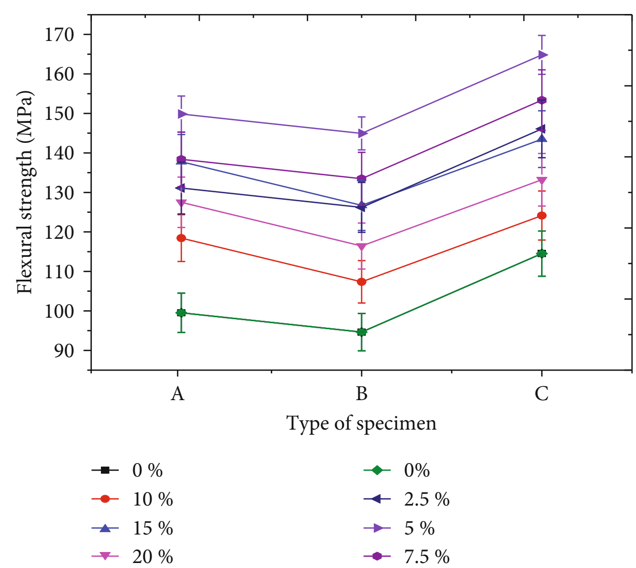


Figure 8: Comparison of flexural strength of microfiller (0 to 20%) and nanofiller (0 to 7.5%) incorporations of hybrid composites.

micro-/nanofiller on the characteristics of hybrid composites is depicted in these pictures. Figure 8 shows that adding TiO_2 microfiller and nanofiller to hybridization composites made with G-K-G-K sequencing increases strength for the first 15 wt% and then begins to decline, indicating that adding TiO_2 microfiller above 15 wt% is not recommended from a reinforcing standpoint. The alternative action of glass fibre causes this sort of behaviour. When adding nanofiller, the strength improves up to 5 wt%, after which the bending behaviour declines [32]. The optimum of G-K-K-G composites increases with the inclusions of micro- and nanofiller up to 15% and 5wt%, correspondingly, before decreasing above those values. The fillers' strength fluctuates between 5% and 10%. The inclusion of fillers raises the toughness of all composites by 20%. When comparing the strength of the nanofiller additions to the strength of the microfiller inclusion, it is evident that the strength of the nanoparticle addition is higher. The difference in strength between 10 wt% microfiller additions and the 15 wt% microfiller additions is quite small. A significant strength increase is seen when nanofiller inclusion of 2.5–5 wt% is considered, making clear the influence of nano-TiO_2 filler addition [33].

In the current research, 5 wt% of nanofillers exhibit the highest mechanical strength compared to microfiller. It was indicated that particulate distribution is ideal in the 5 wt% filler loading even though morphometric pictures and diffusion of nanofillers have been improved, resulting in better crosslink density among both mixture and additives. The above results indicated that additives introduced toughness to the polymeric matrix, yet enhancing the padding proportion beyond a certain moment exacerbated the aggregation of nanoparticles. That also lowered the bonding among both

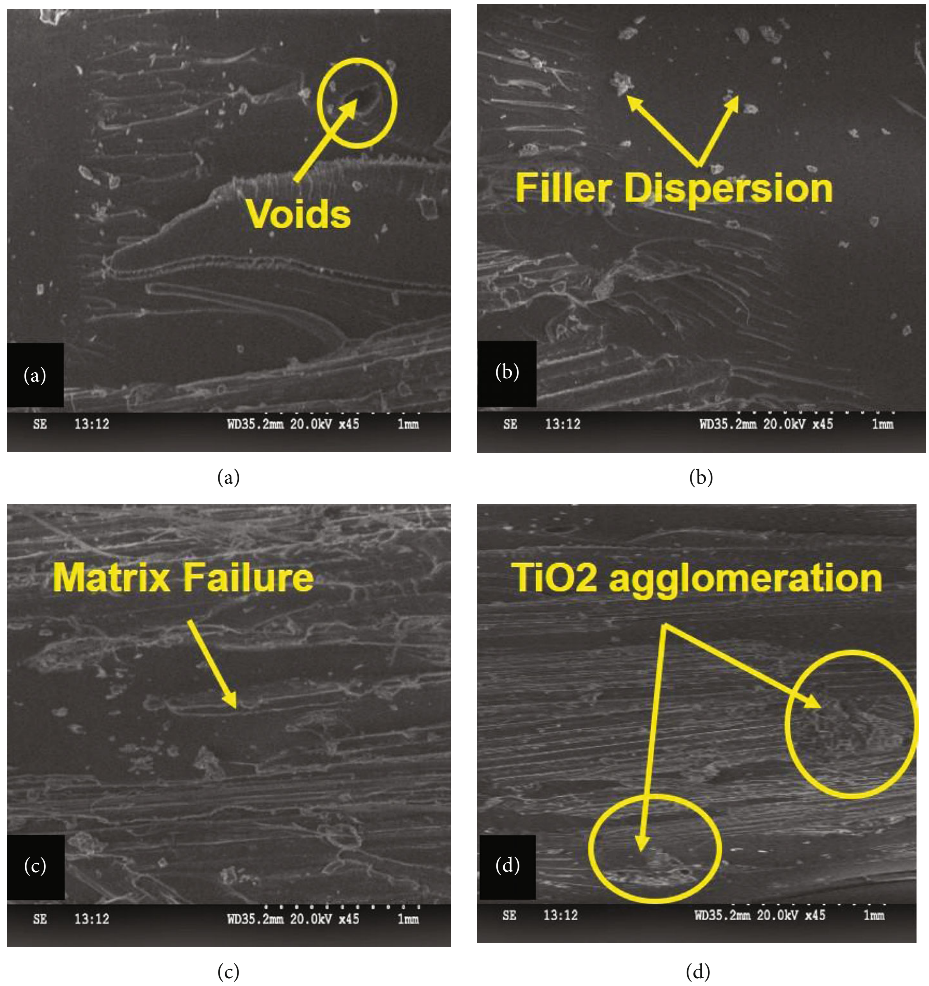


FIGURE 9: Microstructural images of flexural strength: (a) 15 wt% of microfiller, (b) 5 wt% of nanofiller, (c) 20 wt% of microfiller, and (d) 7.5 wt% of nanofiller.

mixture and additives and resulted in a reduction in the composite's mechanical performance. Enhancing the filler proportion complicates the homogeneous distribution of additives, resulting in weak matrix-filler bonding. Figure 9 SEM images were evident for the above findings. The following SEM images show the micro- and nanofiller dispersion in the composite materials. In the case of microfillers, the aggregation problems were raised only at above 15 wt% of filler additions. But the same problems were raised in the nanofiller at above 5 wt%. For those reasons, we cannot add the nanofillers as much of microfillers range.

Figure 8 SEM images show the micro- and nanofiller dispersion in the composite materials. In the case of microfillers, the aggregation problems were raised only at above 15 wt% of filler additions. But the same problems were raised in the nanofiller at above 5 wt%. For those reasons, we cannot add the nanofillers as much of microfillers range. Additionally, it was confirmed through XRD analysis. The interlayer detachment was studied using an X-ray diffractometer on epoxy/TiO_2 specimens. XRD is the main tool for describing the framework of epoxy/TiO_2 nanocomposites. The prepared hybrid samples were run with an XRD from 10° to 60° at

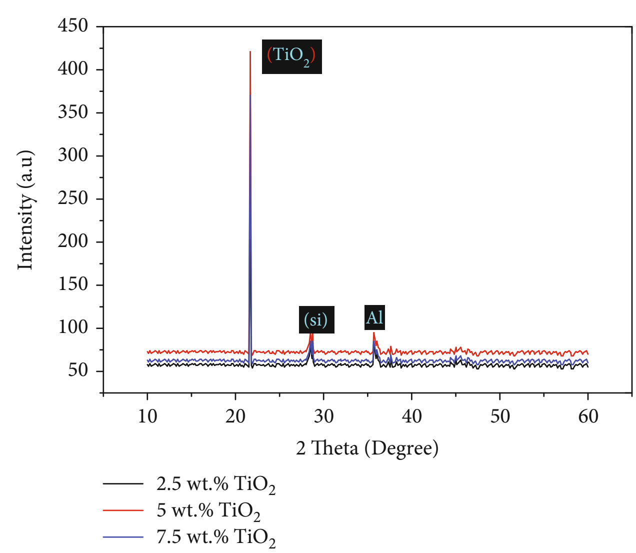
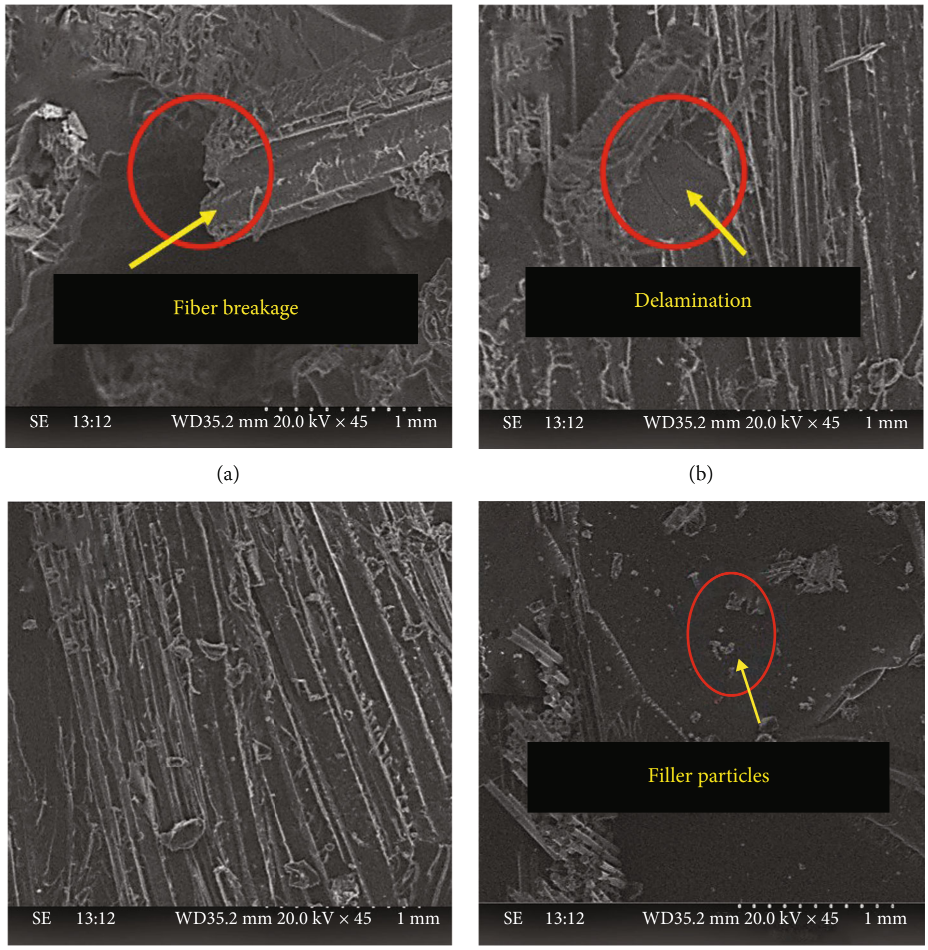


FIGURE 10: XRD analysis of different wt% of nanofiller addition on the hybrid composites.



(a) (b) (c) (d)

FIGURE 11: Microstructural images of (a) glass fibre composites, (b) kenaf fibre composites, (c) kenaf/glass fibre composites, and (d) kenaf/glass/nanofiller composites.

0.02 step sizes and 0.5 s per step. It is indicated in Figure 10. The degree of complexation of nanomaterials was assessed using XRD. The essence of adhesion and the configuration of complexation in nanocomposite were investigated in this study by altering the concentration of nanoparticles. Bragg's law was used to analyze the d-spacing outcomes. The XRD pattern of TiO_2 nanoparticles specimens with various weight ratios (2.5, 5, and 7.5 wt%) did not demonstrate the character trait dorsal introspection. The exclusion of a diffraction pattern suggests that TiO_2 was evenly distributed in the epoxy coating and supports the creation of an exfoliated nanocomposite structural system. The XRD pattern of nanocomposites is depicted in Figure 10.

4. Microstructural Examinations

The morphology pictures of the bending-examined composite are revealed in Figure 11. Figure 11(a) depicts the microstructure of the fibreglass composite. In the glass fibre composites, twisting of the fibreglass due to bending consignment is seen, confirming the flexural data reported in Figures 6 and 7, which would be the highest of all the composites investigated [34]. Compared to composite, kenaf composite exhibited extremely little bending and twisting, as seen in Figure 11(b). The brittle character of the kenaf fibre is defined by a drastic cut of fibre in some spots [35]. Figure 11(c) shows the creation of large fractures preceding breaking in hybridized composite materials without TiO_2 fillers [36]. Figure 11(d) describes the impact of nanofiller inclusion in hybridized materials. Compared to Figure 11(c), it is obvious that the crack creation before fracture is reduced owing to bending strain [37]. This suggests that fillers added to the composite improve the mechanical properties of the hybrid composite [38].

After incorporating functional fillers and reinforcement [39], polymer composites had excellent friction and wear performance [40]. This benefit made them flexible in numerous engineering applications [41].

5. Conclusion

The impact of TiO_2 micro-/nanofiller on the mechanical belongings of kenaf/glass fabric/polymer-based hybrid composites was examined. When comparing the qualities of the nano-TiO_2 filler to the microfiller, it is obvious that the nano-TiO_2 filler improved the mechanical characteristics more. The inclusion of 2.5 wt% nano-TiO_2 into the composite decreases the proportions of porosity.

(i) In microfiller hybrid composites, the void concentrations increase as the filler concentration rises. Because of the filler addition improves the composite's properties by 10% to 20%. The 5 wt% nanofiller-added composites had the enhanced tensile strength of all. Regarding flexural properties, the 5 wt% TiO_2 nanofiller glass-kenaf-kenaf-glass composite is the best alternative to traditional composites. Because of the filler's additives, the composites' flexural strength is increased by 15% to 20%

(ii) Adding 5 wt% nanoparticles to all composites results in the highest mechanical strength. SEM images prove the above findings. It was indicated that particulate distribution is ideal in the 5 wt% filler loading even though morphometric pictures and diffusion of nanofillers have been improved, resulting in better crosslink density among both mixture and additives

(iii) Enhancing the filler percentage complicates the homogeneous distribution of additives, resulting in poor bonding among the mixture and additives. In the case of microfillers, the aggregation problems were raised only at above 15 wt% of filler additions. But the same problems were raised in the nanofiller at above 5 wt%. For those reasons, we cannot add the nanofillers as much of microfillers range

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The researchers acknowledge that they have no conflicts of interests in the publication of this paper.

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References

[1] P. M. Giuliani, O. Giannini, and R. Panciroli, "Characterizing flax fiber reinforced bio-composites under monotonic and cyclic tensile loading," *Composite Structures*, vol. 280, p. 114803, 2022.

[2] M. Ramesh, K. Palanikumar, and K. H. Reddy, "Mechanical property evaluation of sisal-jute-glass fiber reinforced polyester composites," *Composites. Part B, Engineering*, vol. 48, pp. 1–9, 2013.

[3] R. Sepe, F. Bollino, L. Boccarusso, and F. Caputo, "Influence of chemical treatments on mechanical properties of hemp fiber reinforced composites," *Composites. Part B, Engineering*, vol. 133, pp. 210–217, 2018.

[4] M. Ramesh, K. Palanikumar, and K. H. Reddy, "Comparative evaluation on properties of hybrid glass fiber-sisal/jute reinforced epoxy composites," *Procedia Engineering*, vol. 51, pp. 745–750, 2013.

[5] K. R. Sumesh, K. Kanthavel, A. Ajithram, and P. Nandhini, "Bioalumina nano powder extraction and its applications for sisal, coir and banana hybrid fiber composites: mechanical and thermal properties," *Journal of Polymers and the Environment*, vol. 27, no. 9, pp. 2068–2077, 2019.

[6] A. Ashori and Z. Bahreini, "Evaluation of Calotropis gigantea as a promising raw material for fiber-reinforced composite," *Journal of Composite Materials*, vol. 43, no. 11, pp. 1297–1304, 2009.

[7] L. Q. N. Tran, C. A. Fuentes, C. Dupont-Gillain, A. W. Van Vuure, and I. Verpoest, "Wetting analysis and surface characterisation of coir fibres used as reinforcement for composites," *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 377, no. 1-3, pp. 251–260, 2011.

[8] K. G. Ashok, K. Kalaichelvan, and A. Damodaran, "Effect of nano fillers on mechanical properties of luffa fiber epoxy composites," *Journal of Natural Fibers*, vol. 19, no. 4, pp. 1472–1489, 2022.

[9] V. S. Srinivasan, S. R. Boopathy, D. Sangeetha, and B. V. Ramnath, "Evaluation of mechanical and thermal properties of banana-flax based natural fibre composite," *Materials and Design*, vol. 60, pp. 620–627, 2014.

[10] N. Saba, K. Paridah, N. A. Abdan, and N. A. Ibrahim, "Dynamic mechanical properties of oil palm nano filler/kenaf/epoxy hybrid nanocomposites," *Construction and Building Materials*, vol. 124, pp. 133–138, 2016.

[11] S. Öztürk, "Effect of fiber loading on the mechanical properties of kenaf and fiberfrax fiber-reinforced phenol-formaldehyde composites," *Journal of Composite Materials*, vol. 44, no. 19, pp. 2265–2288, 2010.

[12] A. H. P. S. Khalil, M. Masri, C. K. Saurabh et al., "Incorporation of coconut shell based nanoparticles in kenaf/coconut fibres reinforced vinyl ester composites," *Materials Research Express*, vol. 4, no. 3, 2017.

[13] R. Ramasamy, K. Obi Reddy, and A. Varada Rajulu, "Extraction and characterization of Calotropis gigantea bast fibers as novel reinforcement for composites materials," *Journal of Natural Fibers*, vol. 15, no. 4, pp. 527–538, 2018.

[14] S. Yogeshwaran, L. Natrayan, S. Rajaraman, S. Parthasarathi, and S. Nestro, "Experimental investigation on mechanical properties of epoxy/graphene/fish scale and fermented spinach hybrid bio composite by hand layup technique," *Materials Today: Proceedings*, vol. 37, pp. 1578–1583, 2021.

[15] G. Velmurugan and K. Babu, "Statistical analysis of mechanical properties of wood dust filled jute fiber based hybrid composites under cryogenic atmosphere using Grey-Taguchi method," *Materials Research Express*, vol. 7, no. 6, 2020.

[16] V. Swamy Nadh, C. Krishna, L. Natrayan et al., "Structural behavior of nanocoated oil palm shell as coarse aggregate in lightweight concrete," *Journal of Nanomaterials*, vol. 2021, Article ID 4741296, 7 pages, 2021.

[17] K. R. Sumesh and K. Kanthavel, "Grey relational optimization for factors influencing tensile, flexural, and impact properties

of hybrid sisal banana fiber epoxy composites," *Journal of Industrial Textiles*, vol. 51, no. 3, pp. 4441S–4459S, 2022.

[18] L. A. Granda, F. X. Espinach, J. A. Méndez, F. Vilaseca, M. Delgado-Aguilar, and P. Mutjé, "Semichemical fibres of Leucaena collinsii reinforced polypropylene composites: flexural characterization, impact behaviour and water uptake properties," *Composites. Part B, Engineering*, vol. 97, pp. 176–182, 2016.

[19] K. R. Sumesh and K. Kanthavel, "Green synthesis of aluminium oxide nanoparticles and its applications in mechanical and thermal stability of hybrid natural composites," *Journal of Polymers and the Environment*, vol. 27, no. 10, pp. 2189–2200, 2019.

[20] L. Chang and Z. Zhang, "Tribological properties of epoxy nanocomposites:," *Wear*, vol. 260, no. 7-8, pp. 869–878, 2006.

[21] M. Kalil Rahiman, S. Santhoshkumar, S. Mythili, G. E. Barkavi, G. Velmurugan, and R. Sundarakannan, "Experimental analysis of friction stir welded of dissimilar aluminium 6061 and titanium TC4 alloys using response surface methodology (RSM)," *Materials Today: Proceedings*, vol. 65, 2022.

[22] D. P. N. Vlasveld, P. P. Parlevliet, H. E. N. Bersee, and S. J. Picken, "Fibre-matrix adhesion in glass-fibre reinforced polyamide-6 silicate nanocomposites," *Composites. Part A, Applied Science and Manufacturing*, vol. 36, no. 1, pp. 1–11, 2005.

[23] J. Chandradass, M. R. Kumar, and R. Velmurugan, "Effect of nanoclay addition on vibration properties of glass fibre reinforced vinyl ester composites," *Materials Letters*, vol. 61, no. 22, pp. 4385–4388, 2007.

[24] S. A. Meguid and Y. Sun, "On the tensile and shear strength of nano-reinforced composite interfaces," *Materials and Design*, vol. 25, no. 4, pp. 289–296, 2004.

[25] G. Raghavendra, S. Ojha, S. K. Acharya, and S. K. Pal, "Influence of micro/nanofiller alumina on the mechanical behavior of novel hybrid epoxy nanocomposites," *High Performance Polymers*, vol. 27, no. 3, pp. 342–351, 2015.

[26] D. Veeman, M. S. Sai, P. Sureshkumar et al., "Additive manufacturing of biopolymers for tissue engineering and regenerative medicine: an overview, potential applications, advancements, and trends," *International Journal of Polymer Science*, vol. 2021, Article ID 4907027, 20 pages, 2021.

[27] L. Natrayan and A. Merneedi, "Experimental investigation on wear behaviour of bio-waste reinforced fusion fiber composite laminate under various conditions," *Materials Today: Proceedings*, vol. 37, pp. 1486–1490, 2021.

[28] P. Madhukar, N. Selvaraj, R. Gujjala, and C. S. P. Rao, "Production of high performance AA7150-1% SiC nanocomposite by novel fabrication process of ultrasonication assisted stir casting," *Ultrasonics Sonochemistry*, vol. 58, p. 104665, 2019.

[29] M. Vovk and M. Šernek, "Aluminium trihydrate-filled poly(-methyl methacrylate) (PMMA/ATH) waste powder utilization in wood-plastic composite boards bonded by MUF resin," *BioResources*, vol. 15, no. 2, pp. 3252–3269, 2020.

[30] H. A. Sallal, A. A. Abdul-Hamead, and F. M. Othman, "Effect of nano powder (Al_2O_3-CaO) addition on the mechanical properties of the polymer blend matrix composite," *Defence Technology*, vol. 16, no. 2, pp. 425–431, 2020.

[31] J. Datta, P. Kosiorek, and M. Włoch, "Effect of high loading of titanium dioxide particles on the morphology, mechanical and thermo-mechanical properties of the natural rubber-based composites," *Iranian Polymer Journal*, vol. 25, no. 12, pp. 1021–1035, 2016.

[32] G. Velmurugan, V. S. Shankar, S. Kaliappan et al., "Effect of aluminium tetrahydrate nanofiller addition on the mechanical and thermal behaviour of luffa fibre-based polyester composites under cryogenic," *Environment*, vol. 2022, article 5970534, pp. 1–10, 2022.

[33] N. Saba, M. T. Paridah, K. Abdan, and N. A. Ibrahim, "Effect of oil palm nano filler on mechanical and morphological properties of kenaf reinforced epoxy composites," *Construction and Building Materials*, vol. 123, pp. 15–26, 2016.

[34] L. Natrayan, V. Sivaprakash, and M. S. Santhosh, "Mechanical, microstructure and wear behavior of the material AA6061 reinforced SiC with different leaf ashes using advanced stir casting method," *International Journal of Engineering and Advanced Technology*, vol. 8, pp. 366–371, 2018.

[35] K. Hemalatha, C. James, L. Natrayan, and V. Swamynadh, "Analysis of RCC T-beam and prestressed concrete box girder bridges super structure under different span conditions," *Materials Today: Proceedings*, vol. 37, pp. 1507–1516, 2021.

[36] L. Natrayan, M. Senthil Kumar, and M. Chaudhari, "Optimization of squeeze casting process parameters to investigate the mechanical properties of AA6061/Al 2 O 3/SiC hybrid metal matrix composites by Taguchi and Anova approach," in *Advanced Engineering Optimization Through Intelligent Techniques*, pp. 393–406, Springer, Singapore, 2020.

[37] P. Davim and C. A. Charitidis, "Nanocomposites Materials," *Manufacturing and engineering*, vol. 5, p. 211, 2013.

[38] J. P. Davim, *Modern Mechanical Engineering*, Springer, Berlin, Heidelberg, 2014.

[39] P. Sahoo, S. K. Das, and S. K. Acharya, "2 Tribological aspects of natural fiber composites," *Green Composites*, vol. 22, pp. 33–68, 2017.

[40] P. Davim, *Biomedical Composites: Materials, Manufacturing and Engineering*, Walter de Gruyter, 2013.

[41] M. Rackov, R. Mitrović, and M. Čavić, *Machine and Industrial Design in Mechanical Engineering*, Springer Cham, 2021.