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Research Article

Influences of Nanosilica Particles on Density, Mechanical, and Tribological Properties of Sisal/Hemp Hybrid Nanocomposite

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Focusing on natural fibers are the prominent substitution for synthetic fiber and reinforced into polymer matrices found unique properties such as lightweight, cost-effectiveness, and good mechanical and wear properties. Incompatibility and low adhesive behavior are the primary drawbacks found during the fabrication of natural fiber-bonded polymer matrix composites. The constant weight percentage (10 wt%) of sisal and hemp fiber is treated with a 5% NaOH solution for improving adhesive behavior and bonded with epoxy. The prepared sisal/hemp/epoxy combination is blended with 0 wt%, 3 wt%, 6 wt%, and 9 wt% silica nanoparticles, which results in reduced voids (1.32%) and increased flexural strength (56.98 MPa). Based on the compositions of fiber and reinforcement, the density of the composite varied. Samples 3-6 wt% of silica nanoparticle-blend sisal/hemp/epoxy composite offered maximum tensile and impact strength of 52.16 MPa and 2.1 J. An optical microscope analyzed the tensile fracture surface, and the failure nature was reported. The dry sliding wear performance of composite samples is tested by pin-on-disc setup with a 10 N-40 N load of 10 N interval at 0.75 m/sec. Sample 3 found good wear resistance compared to others.

1. Introduction

Due to beneficial features, the polymer matrix composites were considered significant in structural, sports equipment, automotive interior structure, electrical, housewares, and aerospace [1, 2]. The historical evaluation and measurement of composite properties have varied by choice of processing method, process parameters, choice of reinforcement fiber, and other relevant concerns [3, 4]. The interest in natural fibers from natural plants was more advantageous than synthetic fiber because of ease of availability, accessibility, lightweight, nonexpansive, biodegradability, superior flexural, strength, and renewable [5, 6]. Natural fiber-bonded polymer matrix composites were hybridized with nanofiller additions and found to have significant physical, mechanical, and wear performance compared to conventional materials [7, 8]. Moreover, the life cycle of plantfiber reinforced polymer matrix composites was addressed with various environmental aspects, and its life cycle assessment was proved with the incorporation of plant fiber [9] and to decide the cost and life span of polymer matrix composite [10].

Recently, the growth of hybrid polymer matrix composites containing more than one fiber helps enhance composites' mechanical and wear properties. The composites were prepared by combining polymer or epoxy matrix bonded with reinforcements such as natural, synthetic, natural/synthetic, and fiber/ceramic particles. Moreover, various researchers reported that the adhesive bonding strength between matrix and reinforcement could decide the properties of polymer matrix composite. Fiber with nanofiller (ceramic particles) enhanced the interfacial adhesive action, increasing mechanical strength, and void reduction [11–16]. Cost-effective natural coir, hemp, jute, sisal, bamboo, and natural flax fibers in the polymer matrix composite found an extended life span and biodegradability. The natural fibers were gained from natural biodegradable waste and utilized as filler material for polymer matrix composite fabrication [17–19]. The lightweight automobile components were fabricated from epoxy composite bonded with natural sisal fiber and found to have enhanced mechanical properties as compared to unreinforced polymer composite [20]. The mechanical tensile strength of the hybrid epoxy composite was enhanced via jute/sisal/silica. The presence of silica microparticles in epoxy hybrid composite tensile strength increased by 77% compared to jute/sisal fiber composite [21].

The polyethylene composite was synthesized using montmorillonite/silica nanoparticles blended with wood flour through conventional technique. The presence of silica nanoparticles enhances the composite's rigidity, tensile, and impact strength [22]. The mechanical characteristic of hybrid polyethylene (HDPE) composite was prepared with 5 wt% of natural wood powder and different weight percentages of silica were studied by ASTM. The polyethylene composite containing 3 wt% silica was found to have higher impact strength, and 5 wt% of silica had superior tensile and flexural strength [23].

Similarly, a kenaf/sisal fiber-reinforced epoxy composite was hybridized with a small number of silica nanoparticles and observed to have high mechanical strength [24]. The effect of multiwalled CNT (carbon nanotubes) on the mechanical characteristics of banana/jute/flex fiber-bonded hybrid epoxy composite, which is the increased content of multiwalled CNT in epoxy composite tensile strength, was improved [25]. The ASTM G99 standard studied fly ash-reinforced polymer matrix composites' wear properties for brake applications [26]. The short natural fiber-reinforced thermoplastic composite's thermal and mechanical characteristics were studied by ASTM and found the enhanced flexural strength in 30 wt% of the natural fiber-reinforced composite [27]. Recently, polymer matrix composites were synthesized from chicken feather fiber [28, 29], nonwoven waste cellulose fabric [30], human hair [31], and silicon carbide [32] and found improvement in mechanical performance.

However, the literature studied above shows limited literature on sisal/hemp fiber-bonded epoxy composite. The novelty of the present research is to enhance the adhesive behavior of epoxy composite by adding NaOH-treated natural fiber, and its composite hybridization using different weight percentages of silica nanoparticles helps reduce the voids. The effect of NaOH-treated natural fiber and silica nanoparticles on composite density and mechanical and wear properties is studied. The adhesion effects are proven by mechanical and wear performance. The presence of silica nanoparticles in epoxy composites is expected to enhance tribomechanical characteristics compared to conventional and unreinforced composites. From the above, no report is available on the combinations of sisal/hemp/different weight percentages of silica nanoparticles incorporated in an epoxy composite made by conventional fabrication methods.

Table 1: Compositions of epoxy hybrid nanocomposites.

Matrix/reinforcements/sample		1	2	3	4
Epoxy	Weight percentages in Wt%	80	77	74	71
Sisal fiber		10			
Hemp fiber		10			
Silica nanoparticles		0	3	6	9

2. Experimental Details

2.1. Details of Material Selection. Araldite epoxy resin (AW106) and hardener (HV935) are chosen as matrix materials. Natural sisal and hemp fibers (10-12 mm fiber length) are selected as filler materials and have good mechanical strength, better thermal properties, more durability, UV light resistance, and good dying capabilities [24]. A silica nanoparticle of 50 nm is chosen as a secondary filler material, enhancing the composite's mechanical and wear properties.

2.2. Processing of Natural Fibers. Initially, the natural sisal and hemp fibers were cleaned with distilled water in test room conditions and dried at ambient temperature (27°C) for 48 hrs. After the processing, each fiber was kept in a separate bowl containing 5% NaOH, soaked for 24 hrs to remove the waste dust particles, and cured as clean fiber. The NaOH chemical treatment helps to increase the adhesive and interlocking properties between the matrix and reinforcements [25]. The NaOH-treated fibers were dried in test room condition for 24 hrs. After the NaOH treatment, the fibers were immersed in distilled water for 30mins and then dried via oven heat for 10 hours duration at 65°C temperature. Finally, the fibers were sheared to 10-12 mm length via a fine cutter and used as filler phase. The constitution of epoxy hybrid composite fabrication weight percentage is tabulated in Table 1.

2.3. Fabrication of Composites. Figure 1 presents the actual flow process fabrication layout for epoxy hybrid nanocomposite containing constant weight percentages (10 wt%) of sisal/hemp fiber and hybridization with different weight percentages of silica nanoparticles, as the details were mentioned in Table 1.

The 10 : 1 ratio of epoxy resin and hardener was blended using a mechanical stirrer. The chemically treated chopped sisal and hemp fibers were weighed by a digital weighing machine and mixed into an epoxy resin blend pool. An applied speed of 500 rpm for 30 mins uniformly stirred the epoxy resin pool and natural fibers. Meanwhile, the silica nanoparticles were preheated by a muffle furnace to remove

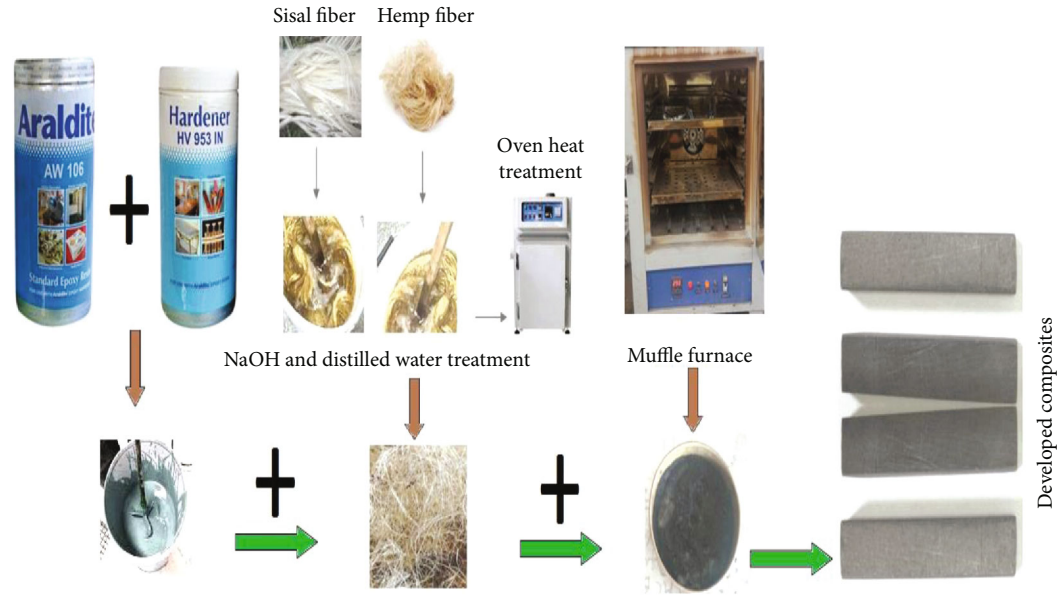

Figure 1: Actual flow process fabrication layout for epoxy hybrid nanocomposite.

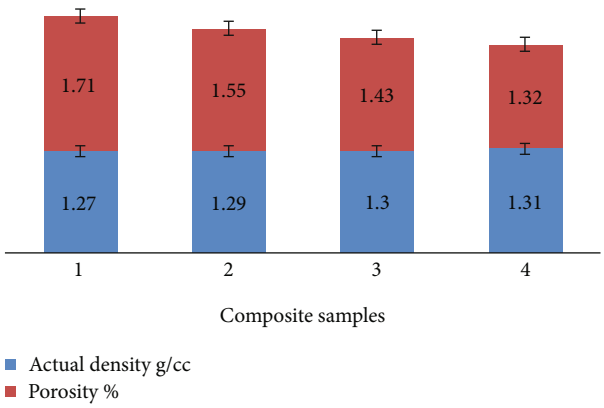

Figure 2: Density and porosity of developed epoxy hybrid nanocomposites.

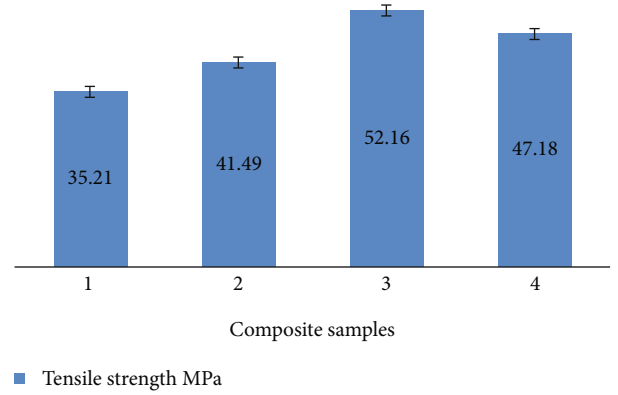

Figure 3: Tensile strength of developed epoxy hybrid nanocomposites.

the moisture content. After the blending process, the externally preheated silica nanoparticles were forced to epoxy and blend with continuous stir action, and 70°C raised their temperature via an electrical heater, increasing the composite's adhesive properties. The epoxy resin pool containing natural fibers and silica nanoparticles was blended at 500 rpm stir speed for 20 mins at a temperature range of 55°C to 70°C. Finally, blended compositions were transferred to a steel mold with an applied load of 0.5 tons.

2.4. Test Details. The rule of mixture measures the density of the composite, and its voids are estimated by the Archimedes principle at test room conditions. The Instron 3367 model, a tensile/compression testing machine, was utilized to evaluate composites' tensile and flexural strength at a 5 mm/min cross-slide speed. The tensile and flexural strengths of the composite were followed by the standard of ASTM D638 and ASTM D790 standards [15, 23]. The IT30-impact machine performed the impact toughness as per ASTM D6110. The wear performance of the developed composite is evaluated with hardened gray cast-iron material under 10 N, 20 N, 30 N, and 40 N average loads at 0.75 m/sec sliding velocity, followed by the ASTM G99 standard [3, 11, and 26].

3. Results and Discussions

3.1. Density and Porosity Percentages of Epoxy Hybrid Nanocomposites. The density and porosity percentages of epoxy hybrid nanocomposite synthesized using sisal/hemp fiber bonded with different weight percentages of silica nanoparticles results are addressed in Figure 2. The principle of Archimedes measured the actual experimental density of an epoxy hybrid nanocomposite. The actual experimental density of epoxy hybrid nanocomposite without silica nanoparticles was 1.27 ± 0.28 g/cc, and the impact of silica nanoparticles on the epoxy hybrid nanocomposite density was progressively increased by 1.29 ± 0.21 g/cc, 1.30 ± 0.11, and 1.31 ± 0.12 g/cc of 3 wt%, 6 wt%, and 9 wt% of silica

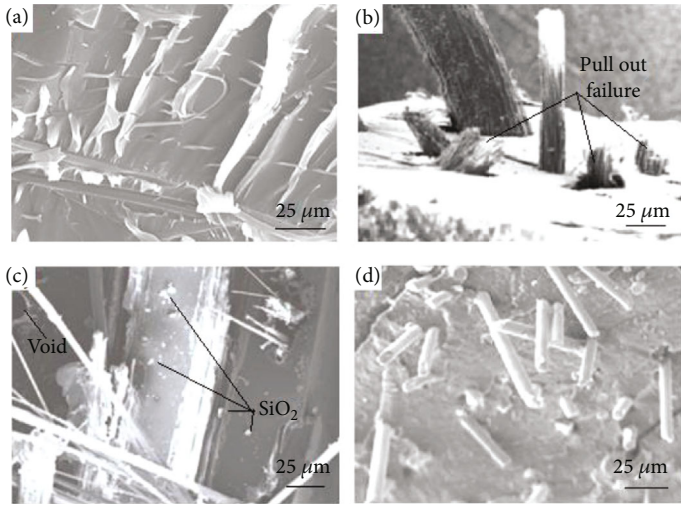

Figure 4: Tensile fracture surface morphology. (a) Sample 1. (b) Sample 2. (c) Sample 3. (d) Sample 4.

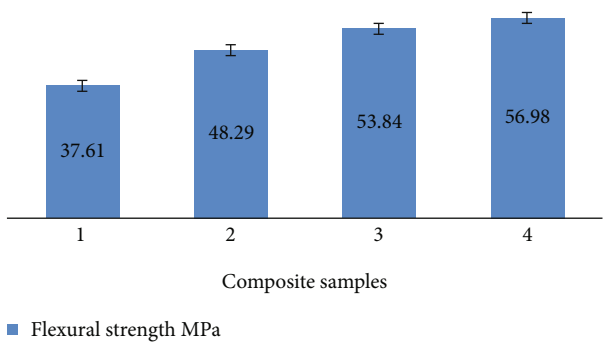

Figure 5: Flexural strength of developed epoxy hybrid nanocomposites.

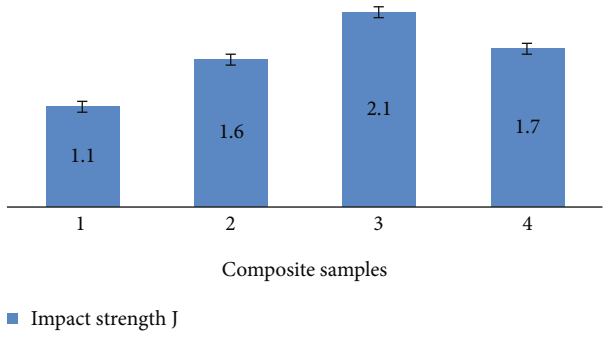

Figure 6: Impact strength of developed epoxy hybrid nanocomposites.

nanoparticles, respectively. The improvement in epoxy composite density was mainly featured by the choice of silica nanoparticle content and low-density epoxy resin. However, the porosity percentages of epoxy hybrid composites decreased with increased silica nanoparticles due to its effective dispersion of silica nanoparticles in the epoxy resin.

The uniform presence of silica nanoparticles was the main reason for the composite's increased density and reduced porosity. It helps to improve the mechanical and tribological properties [26].

3.2. Effect of Silica Nanoparticles on Tensile Strength of Epoxy Hybrid Nanocomposites. ASTM D638 standards evaluated the tensile strength of developed epoxy composites through the Instron 3367 tensile testing machine with an applied crosshead speed of 5 mm/min. Figure 3 illustrates the tensile strength of an epoxy composite reinforced with 10 wt% of sisal and 10 wt% of hemp fiber via conventional technique. The epoxy/sisal/hemp combinations were enriched with silica nanoparticles via a uniform stir speed of 500 rpm. The tensile strength of an unreinforced epoxy/sisal/hemp fiber composite was 35.21 ± 1.34 MPa, and 3 wt% of silica nanoparticles incorporated into an epoxy hybrid nanocomposite was observed at 41.49 ± 2.11 MPa. There was evidence of silica nanoparticles present.

The constitutions of 6 wt% of silica nanoparticles in the hybrid nanocomposites identified the maximum tensile strength as 52.16 ± 1.91 MPa. The increase in the tensile of the composite was due to the good interfacial bonding between epoxy and sisal/hemp fiber was increased by the presence of silica nanoparticles. The minor porous was occupied and silica nanoparticles increased its composite bonding strength. The tensile strength of the composite varied due to the processing, selection of matrix, and reinforcement [15, 20]. Further additions of silica nanoparticles into epoxy composite found decreases in tensile strength of 47.18 ± 1.87 MPa. However, the 6 wt% of silica nanoparticles-reinforced epoxy composite was found to have higher tensile strength and increased by 48.13% compared to sample 1 (unreinforced epoxy/sisal/hemp composite).

3.3. Tensile Fracture Surface Analysis. Figure 4 represents the tensile fracture micrograph of a natural fiber-reinforced epoxy composite with and without silica (SiO_2) nanoparticles. Figure 4(a) shows the tensile fracture surface micrograph of an epoxy/natural fiber composite without silica content. It showed elongated failure during the tensile test, and the layers are deflecting with their natural fiber. The tensile failure of sample 2 is illustrated in Figure 4(b). The micrograph indicates the pullout failure during the high tensile force. However, the silica nanoparticles were effectively

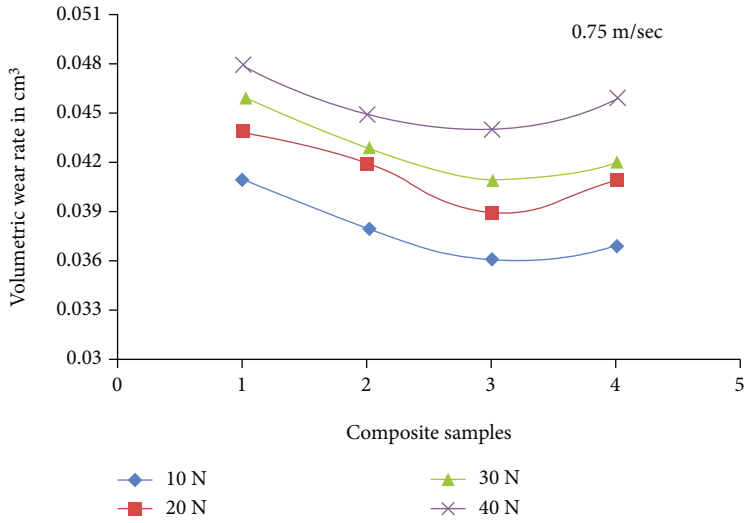

Figure 7: Volumetric wear rate of developed epoxy hybrid nanocomposites.

bonded with the epoxy layer, and the fracture surface of sample 3 is shown in Figure 4(c). A few voids were found during the evaluation of the tensile fracture surface and were due to the air gap. Figure 4(d) indicates the tensile fracture surface morphology of sample 4 composite contained 9 wt% of silica particles. It clearly shows adequate bonding with uniformly distributed SiO_2 particles in epoxy and also formed the microcrack during high tension.

3.4. Effect of Silica Nanoparticles on Flexural Strength of Epoxy Hybrid Nanocomposites. The flexural strength of epoxy hybrid composites reinforced with different weight percentages of silica nanoparticles was evaluated by ASTM D790 standards, and its values are summarized in Figure 5. The flexural strength of epoxy composite without silica nanoparticles showed 37.61 ± 1.09 MPa, and it was improved by 28.3% with the addition of 3 wt% of silica nanoparticles. The flexural strength of sample 3 hybrid nanocomposite was 53.84 ± 2.13 MPa, which increased by 43.15% compared to sample 1 epoxy composite. The higher flexural strength of 56.98 ± 1.12 MPa was noted by 6 wt% of silica nanoparticle-reinforced epoxy composite. It was increased by 51.5% compared to sample 1 epoxy composite without silica nanoparticles. However, the epoxy composite's improved fiber orientations and silica nanoparticle content must attain maximum flexural strength. One of the researchers reported a similar tendency while evaluating a silica-reinforced sisal/glass fiber hybrid composite [20].

3.5. Effect of Silica Nanoparticles on the Impact Strength of Epoxy Hybrid Nanocomposites. The Charpy impact energy on developed epoxy composites with and without silica nanoparticles was experimentally measured in ASTM D6110 standards, and its measured values are illustrated in Figure 6. The inclusion of silica nanoparticles in the epoxy composites impact strength was progressively improved with constant weight percentages of sisal and hemp fiber. It was noted from Figure 6 bar chart that the epoxy composite contained 10 wt% of each sisal and hemp fiber and offered an impact strength of 1.1 ± 0.5 J, and the epoxy/sisal/hemp fiber composite was hybridized with different weight percentages of silica nanoparticles. The impact strength of the composite was increased from 1.6 ± 0.45 J to 2.1 ± 0.75 J with the incorporation of 3 wt% and 6 wt% of silica nanoparticles, respectively. The increase in impact strength of the composite was due to the presence of sisal and hemp fibers which were able to resist the high impact load because both sisal and hemp fibers have good mechanical properties. Moreover, the adequate void-free interfacial bonding quality has increased by incorporating silica nanoparticles. With more than 6 wt% of silica nanoparticles, the impact strength of the composite was reduced by 23.5% compared to sample 3. The decreased impact strength was due to the higher content of silica which led to its brittle nature [20]. The variation in impact strength was due to fiber orientations and the processing method [23, 24].

3.6. Effect of Silica Nanoparticles on the Wear Rate of Epoxy Hybrid Nanocomposites. The wear rate characteristics of a developed hybrid nanocomposite containing different weight percentages of silica nanoparticles were investigated by ASTM G99 standards through a pin-on-disc wear tester consisting of a hardened steel counter-disc with an applied load of 10-40 N of a 10 N interval under 0.75 m/sec sliding velocity. Figure 7 shows the wear rate of developed epoxy hybrid nanocomposited with and without silica nanoparticles.

It was observed in Figure 6 that the volumetric wear rate of epoxy hybrid nanocomposites increased with improved average load from 10 N to 40 N, respectively. The volumetric wear rate of sample 1 epoxy composite without silica nanoparticles was increased progressively from 0.041 cc to 0.048 cc. While the incorporations of silica nanoparticles in the epoxy composite volumetric wear rate also increased gradually but were lower than the sample 1 composite, similarly, samples 2 and 3 observed a reduction in wear rate with the addition of silica nanoparticles by 3 wt% and 6 wt%, respectively. Due to the presence of nanosilica particles that resisted the indentation against the high sliding

speed, natural fibers performed better in elongation. The natural fibers had good tensile and Young's modulus characteristics that resist or withstand the maximum frictional force [18, 25]. The content of silica nanoparticles of more than 6 wt% showed an increased volumetric wear rate. It was due to increased silica content that led to the breaking and deboning of the fiber layer. However, the content of nanosilica particles enhanced the composite's wear properties, and sample 3 was identified as having a low volumetric wear rate compared to all. It was reduced by 9% with the applied 40 N load and 0.75 m/sec sliding velocity.

4. Conclusions

The epoxy composite containing sisal and hemp fiber was successfully hybridized using different weight percentages of silica nanoparticles, and its physical, mechanical, and wear properties were enhanced. The test results and main conclusions are made below.

(i) The epoxy/sisal/hemp composite was enriched with the addition of nanosilica particles at 0, 3, 6, and 9 wt% via conventional processing to minimize the cost

(ii) The composite density gradually increased, and sample 4 found a higher density of 1.31 ± 0.12 g/cc with a reduced porosity of 1.32%

(iii) The epoxy composite containing 6 wt% of nanosilica particles identified higher tensile and impact strength. It was enriched by 48.13% and had 1.9 times tensile and impact strength compared to sample 1 unreinforced silica nanoparticles epoxy composites

(iv) The composite contained 6 wt% of silica nanoparticles owing to good flexural strength and increased by 51.5% compared to sample 1 epoxy composite without silica nanoparticles

(v) The influences of silica nanoparticles in the epoxy composite have reduced the volumetric wear rate, and sample 3 was observed as good wear behavior on high load and sliding speed compared to others

(vi) In the future, silica will be derived from natural wastes like rice husk ash, bamboo leaves, and others and utilized as a secondary phase filler material for polymer matrix composites

(vii) The natural fiber is extracted from various natural waste leaves and chemically treated to increase the properties of fiber instead of synthetic fiber

Data Availability

All the data required are available within the manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] H. S. Kim, J. U. Jang, H. Lee et al., "Thermal management in polymer composites: a review of physical and structural parameters," *Advanced Engineering Materials*, vol. 20, no. 10, article 1800204, 2018.

[2] M. J. Mochane, T. E. Motaung, and S. V. Motloung, "Morphology, flammability, and properties of graphite reinforced polymer composites. Systematic review," *Polymer Composites*, vol. 39, no. S3, pp. E1487–E1499, 2018.

[3] S. Pradhan, S. K. Acharya, and V. Prakash, "Mechanical, morphological, and tribological behavior of Eulaliopsis binata fiber epoxy composites," *Journal of Applied Polymer Science*, vol. 138, no. 12, p. 50077, 2021.

[4] J. Chen, L. Yan, W. Song, and D. Xu, "Thermal and electrical properties of carbon nanotube-based epoxy composite materials," *Material Research Express*, vol. 5, no. 6, article 65051, 2018.

[5] M. Ramesh, K. Palanikumar, and K. H. Reddy, "Plant fibre based bio-composites: sustainable and renewable green materials," *Renewable and Sustainable Energy Reviews*, vol. 79, pp. 558–584, 2017.

[6] Natural fibers and their composites, "Natural fibers and their composites," *Tribology of Natural Fiber Polymer Composites*, vol. 5, pp. 1–58, 2008.

[7] P. Jagadeesh, M. Puttegowda, Y. G. T. Girijappa, S. M. Rangappa, and S. Siengchin, "Effect of natural filler materials on fiber reinforced hybrid polymer composites: an overview," *Journal of Natural Fibers*, vol. 19, no. 11, pp. 4132–4147, 2022.

[8] N. Saba, P. Tahir, and M. Jawaid, "A review on potentiality of nano filler/natural fiber filled polymer hybrid composites," *Polymers*, vol. 6, no. 8, pp. 2247–2273, 2014.

[9] M. Ramesh, C. Deepa, L. R. Kumar, M. R. Sanjay, and S. Siengchin, "Life-cycle and environmental impact assessments on processing of plant fibres and its bio-composites: a critical review," *Journal of Industrial Textiles*, vol. 51, Supplement 4, pp. 5518S–5542S, 2022.

[10] S. Jayavani, H. Deka, T. O. Varghese, and S. K. Nayak, "Recent development and future trends in coir fiber-reinforced green polymer composites: review and evaluation," *Polymer Composites*, vol. 37, no. 11, pp. 3296–3309, 2016.

[11] M. Gupta, "Thermal and dynamic mechanical analysis of hybrid jute/sisal fibre reinforced epoxy composite," *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, vol. 232, no. 9, pp. 743–748, 2018.

[12] R. Z. A. A. Ramadhan, A. R. Abu Talib, A. S. Mohd Rafie, and R. Zahari, "High velocity impact response of Kevlar-29/epoxy and 6061-T6 aluminum laminated panels," *Materials & Design*, vol. 43, pp. 307–321, 2013.

[13] P. Sahu and M. K. Gupta, "Sisal (Agave sisalana) fibre and its polymer-based composites: a review on current developments," *Journal of Reinforced Plastics and Composites*, vol. 36, no. 24, pp. 1759–1780, 2017.

[14] M. Ramesh, L. N. Rajeshkumar, N. Srinivasan, D. V. Kumar, and D. Balaji, "Influence of filler material on properties of

fiber-reinforced polymer composites: a review," *e-Polymers*, vol. 22, no. 1, pp. 898–916, 2022.

[15] C. Dong, "Review of natural fibre-reinforced hybrid composites," *Journal of Reinforced Plastics and Composites*, vol. 37, no. 5, pp. 331–348, 2018.

[16] S. Doagou-Rad, A. Islam, and T. D. Merca, "An application-oriented roadmap to select polymeric nanocomposites for advanced applications: a review," *Polymer Composites*, vol. 41, no. 4, pp. 1153–1189, 2020.

[17] R. A. Braga and P. A. Magalhaes, "Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites," *Material Science and Engineering Part C*, vol. 56, pp. 269–273, 2015.

[18] K. Bledzki, S. Reihmane, and J. Gassan, "Properties and modification methods for vegetable fibers for natural fiber composites," *Journal of Applied Polymer Science*, vol. 59, no. 8, pp. 1329–1336, 1996.

[19] M. Shamsuyeva, O. Hansen, and H. J. Endres, "Review on hybrid carbon/flax composites and their properties," *International Journal of Polymer Science*, vol. 2019, Article ID 9624670, 17 pages, 2019.

[20] B. T. Ferreira, L. J. da Silva, T. H. Panzera, J. C. Santos, R. T. S. Freire, and F. Scarpa, "Sisal-glass hybrid composites reinforced with silica microparticles," *Polymer Testing*, vol. 74, pp. 57–62, 2019.

[21] A. M. Kazi, D. V. A. Ramasastry, and S. Waddar, "Characterization of interwoven roselle/sisal fiber reinforced epoxy composites," *Polymer Composites*, vol. 43, no. 3, pp. 1421–1428, 2022.

[22] J. Jiang, C. Mei, M. Pan, and J. Cao, "Improved mechanical properties and hydrophobicity on wood flour reinforced composites: incorporation of silica/montmorillonite nanoparticles in polymers," *Polymer Composites*, vol. 41, no. 3, pp. 1090–1099, 2020.

[23] T. Buddi, B. N. Rao, S. K. Singh, R. Purohit, and R. S. Rana, "Development and analysis of high density poly ethylene (HDPE) nano SiO2and wood powder reinforced polymer matrix hybrid nano composites," *Journal of Experimental Nanoscience*, vol. 13, Supplement 1, pp. S24–S30, 2018.

[24] L. M. G. Vieira, J. C. . Santos, T. H. Panzera et al., "Hybrid composites based on sisal fibers and silica nanoparticles," *Polymer Composites*, vol. 39, no. 1, pp. 146–156, 2018.

[25] K. Mohan and T. Rajmohan, "Fabrication and characterization of MWCNT filled hybrid natural fiber composites," *Journal of Natural Fibers*, vol. 14, no. 6, pp. 864–874, 2017.

[26] V. Ahlawat, S. Kajal, and P. Anuradha, "Tribo-performance assessment of milled fly ash brake friction composites," *Polymer Composites*, vol. 41, no. 2, pp. 707–718, 2020.

[27] Y. Kısmet and A. Dogan, "Characterization of the mechanical and thermal properties of rape short natural-fiber reinforced thermoplastic composites," *Iranian Polymer Journal*, vol. 31, no. 2, pp. 143–151, 2022.

[28] A. Verma, P. Negi, and V. K. Singh, "Physical and thermal characterization of chicken feather fiber and crumb rubber reformed epoxy resin hybrid composite," *Advances in Civil Engineering Materials*, vol. 7, no. 1, pp. 20180027–20180557, 2018.

[29] A. Verma, P. Negi, and V. K. Singh, "Experimental analysis on carbon residuum transformed epoxy resin: chicken feather fiber hybrid composite," *Polymer Composites*, vol. 40, no. 7, pp. 2690–2699, 2019.

[30] S. Rastogi, A. Verma, and V. K. Singh, "Experimental response of nonwoven waste cellulose fabric–reinforced epoxy composites for high toughness and coating applications," *Materials Performance and Characterization*, vol. 9, no. 1, article 20190251, 2020.

[31] A. Verma and V. K. Singh, "Mechanical, microstructural and thermal characterization of epoxy-based human hair–reinforced composites," *Journal of Testing and Evaluation*, vol. 47, no. 2, pp. 1193–1215, 2019.

[32] N. Bisht, A. Verma, S. Chauhan, and V. K. Singh, "Effect of functionalized silicon carbide nano-particles as additive in cross- linked PVA based composites for vibration damping application," *Journal of Vinyl and Additive Technology*, vol. 27, no. 4, pp. 920–932, 2021.