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Research Article

Influence of Epoxy/Nanosilica on Mechanical Performance of Hemp/Kevlar Fiber Reinforced Hybrid Composite with an Ultrasonic Frequency

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Ultrasonic vibration was employed in blending the nanosilica into epoxy resin to manufacture hemp/kevlar/nanosilica-based epoxy composites, with an ultrasonic occurrence of 20 kHz and a 900 W capacity of power. An ultrasonic probe was utilized to ensure the consistent dispersion of the nanoparticles in the epoxy. The mechanical characteristics of hemp/kevlar fiber reinforced with epoxy/nanosilica in a mat form have been studied. Hand layup procedures were used to create these composites, including varying weight % of nanosilica and variable fiber stacking sequencing. The different weight % are 3, 6, and 9, and the stacking sequences are B, C, and D. The effectiveness of ultrasonic irradiation on mechanical characteristics was investigated and related. The inclusion of 6 wt.% of SiO_2 to the B type resulted in a 25% rise in tension and a 37% in bending. The addition of 6 wt.% silica to the C-type hybridization nanocomposite results in a 34% rise in tension and a 38% rise in bending. Extreme tension behavior is attained at 6 wt.% SiO_2 with epoxy with the B type piling order, and extreme bending behavior is obtained at 6 wt.% SiO_2 with the C type piling order. A B-type model composite with a 6-wt.% SiO_2 addition performed better in hygroscopic than A, C, and D type model composites. An SEM is utilized to observe the microstructure of shattered materials.

1. Introduction

In today's hybrid environment, hybrid composites play an essential and innovative role in various industrial applications. A hybrid composite comprises a polymer matrix, fibers, and fillers for reinforcement. Because of its low-cost, toughness proportion, and excellent mechanical characteristics, a lot of research is going on to create new hybrid composites [1]. Due to their improved mechanical properties, lower weightiness, exceptional elasticity, oxidation resistance, and simplicity of fabrication, artificial fiber-reinforced composite materials have become increasingly popular [2]. Kevlar fiber, one of the most durable manufactured fibers, offers exceptional features among artificial fibers. Kevlar fiber is employed in various industries and high-tech equipment, including rotating blades and explosive weaponry [3]. Oil palms, cotton, flax, jute, banana leaf, coir, wood, and lumber seem to be the most often utilized natural fibers in the polymer fabrication of composites.

On the other hand, natural fibers provide significant economic and productivity benefits over artificial fibers like glass, nylon, and graphite [4]. On the other hand, natural fibers have low mechanical qualities such as tension and bending. Consequently, utilizing natural fiber alone in a polymeric resin is inadequate to meet all scientific criteria for biocomposites reinforcement [5]. As a result, our present aim is to create novel hybrid materials. The strength of composites is affected by several parameters, including the fiber direction, the reinforcement-to-resin ratio, and the human connection between the fiber and the matrices [6]. When mechanical loads, such as tension and bend stresses, are introduced to polymeric materials, they are more prone to failure. The mechanical characteristics of epoxy-reinforced hemp/glass fibers were investigated by Palanikumar et al. [7]. Compared to hybrid composites, samples reinforced with glass fibers had the highest strength. Prajapati and Gupta [8] established the physiomechanical study of fiberglass-based SiO_2 epoxy mixture composites. He discovered that fiberglass with a 25% content and nanosilica with a 3% content had superior mechanical properties to another weight %. Nanosilica added to glass fiber improves its characteristics. Shakuntala et al. [9] and colleagues investigated a polymeric matrix's mechanical and rheological characteristics filled with wood apple shell particles. It was also discovered that using indigenous edible shells as a filler improved the machinability features. Incorporating Nanofillers into matrices is a critical step in producing nanocomposite; there are several methods for doing so, including shear mixing, mechanically churning, and ultrasonicating. When the resins and nanomaterials are subjected to high shear forces, shear mixing necessitates using two or four mills [3, 10]. However, that method has the disadvantage of having a limited resin supply in the mills. Mechanical churning also aids in the formation of cavities. The nanofillers must first be mixed with a mechanical stir before being ultrasonic. Compared to the individual statistics, the combined results offer good mechanical characteristics. The most popular approach, ultrasonication, has already shown great potential in dissolving particle groups and improving solution consistency [11].

The behavior of resolutions transformed from non-Newtonian to Newtonian in ultrasonic irradiation duration is one of the sonicator's most important features [12]. Ultrasonic processing is utilized for various purposes, including nanoparticle dispersion in base fluids, particulate deagglomeration, particulate reduction in size, particulate mix and precipitate, and surface functionality, among others. Because the high rate of ultrasonic surfs travels over slighter packages, ultrasonic radiation is used to disperse fillers in the polymeric matrices. As the sonication duration increases, such small packages of nanofillers gradually exfoliate into smoothly decreased bundles and then develop completely as single nanobased fillers in the polymers [13, 14].

Table 1: Mechanical properties of reinforcements and matrix.

Sl. No.	Properties	Hemp fiber	Kevlar fiber	Epoxy resin
1	Hemi cellulose (%)	18.6-23.2	—	—
2	Cellulose (%)	71.4-75.2	—	—
3	Lignin (%)	3.7-5.7	—	—
4	Density (g/cm^3)	1.47	1.5-2.25	1.16
5	Tensile strength (MPa)	690-850	62000	8-19
6	Young's modulus (GPa)	68-70	70-72	0.58
7	Elongation (%)	2-4.1	2.8-3.3	1.6

Therefore, it is clear from the literature that little research has been done on hybrid composites, certain stacking sequences, and nanosilica as a filler. As a result, the major goal of this research is to build a novel mixture that is a combination of organic and artificial fibers with a changed piling order of hemp and kevlar mat fiber incorporated with nano-SiO_2-based epoxy composites for manufacturing the cheapest materials. Table 1 shows some mechanical possessions of hemp and kevlar fibers.

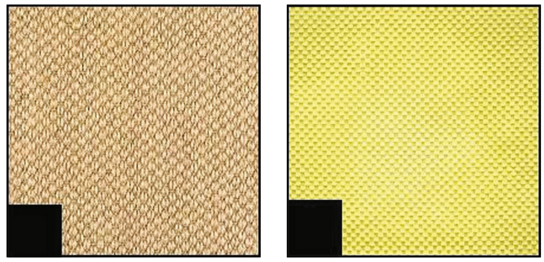
2. Investigational Resources

2.1. Materials. In the fabrication of nanocomposite, hemp and Kevlar fiber are used as reinforcement materials, nanosilica is used as a particle material, and unsaturated epoxy is used as a matrix. Both reinforcements and matrix materials were procured from Jayanthi Fiber Industry in Chennai. Naga chemicals limited in Chennai, Tamil Nadu, India, supplied the nanosilica particles.

Figures 1(a) and 1(b) demonstrate the photographic image of hemp and kevlar fiber mate. Figures 2(a) and 2(b) show the photographic image of nanosilica powder and its chemical structure.

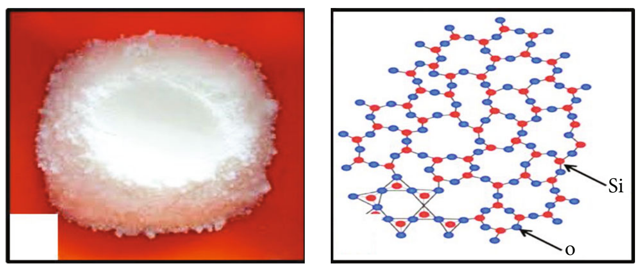
2.2. NaOH Processing. To eliminate any unwanted contamination, the raw hemp fibers will be cleaned separately at 60 to 75°C for 1 hour with 1 to 2% detergent solutions, then rinsed with purified water, and cured in an oven at 75°C for 2 hours. The cleaned fibers were then submerged in 5% solutions of NaOH for 4 hours at 30°C. Alkali-treated fibers were completely cleaned with purified water and dehydrated by ambient conditions.

2.3. Composite Sample Fabrication. The nanosilica and epoxy were combined in the first phase using a mechanical churning procedure for 15 min to combine matrices and fillers. Using ultrasonic vibrations, the ultrasonicator is then used to disperse the filler into the matrix. Various weight proportions of nanosilica filler loading, like 3, 6, and 9 wt.% were employed to create a nanocomposite. The SiO_2 and epoxy combination were positioned in a glass pipette, stirred mechanically, and maintained in an elevated ultrasonic bath for 45 minutes on pulse mode.



(a) (b)

Figure 1: (a) Photographic image of hemp. (b) Kevlar fiber mate.



(a) (b)

Figure 2: (a) Photographic image of nanosilica powder. (b) Chemical structure of silica.

Once the process was completed, the hand layup approach was used to prepare epoxy/nanosilica/hemp/kevlar composites. Four levels of fiber were created, with the layering sequences of kevlar-hemp-kevlar, kevlar-hemp-kevlar, kevlar-hemp-kevlar, kevlar-hemp-kevlar, kevlar-hemp-kevlar, hemp-kevlar-hemp, and hemp-kevlar-hemp shifting. Inside the mould, hemp and kevlar fiber layers are inserted. After that, the previously prepared epoxy/nanosilica combination was put into the mould. The preliminary surfaces were bonded till the entire adhesive was engrossed. Then, next film was coated till wet with different epoxy/nanosilica mix. After that, a roller was used to forcefully crush the specimen to a thickness of about 3 mm. The same processes were sustained till entire folds were enclosed. Composite specimens were cured at atmospheric conditions for one day beforehand being sliced into appropriate sizes for tension and bending strength testing, according to the ASTM. Table 2 lists the specimen numbers based on the stacking sequence. Figures 3(a)–3(c) show the fabrication of bio-based nanocomposites by using the hand layup method.

Table 2: Stacking sequence arrangement of nanocomposites.

Sl. No.	Specimen symbol	Stacking sequence
1	A	Plain epoxy resin
2	B	Kevlar-hemp-hemp-kevlar
3	C	Kevlar- hemp-kevlar-hemp
4	D	Hemp-kevlar-kevlar-hemp

2.4. Testing. The fabricated composite specimens were cut to the ASTM standard of D 638-03 replicas with a dimension of $150 \times 15 \times 3$ mm for tensile testing and ASTM D-790 (width 10 mm, length 125 mm, and thickness 3 mm) for flexural testing. Figure 4 reveals the photographic images of tensile and flexural specimens.

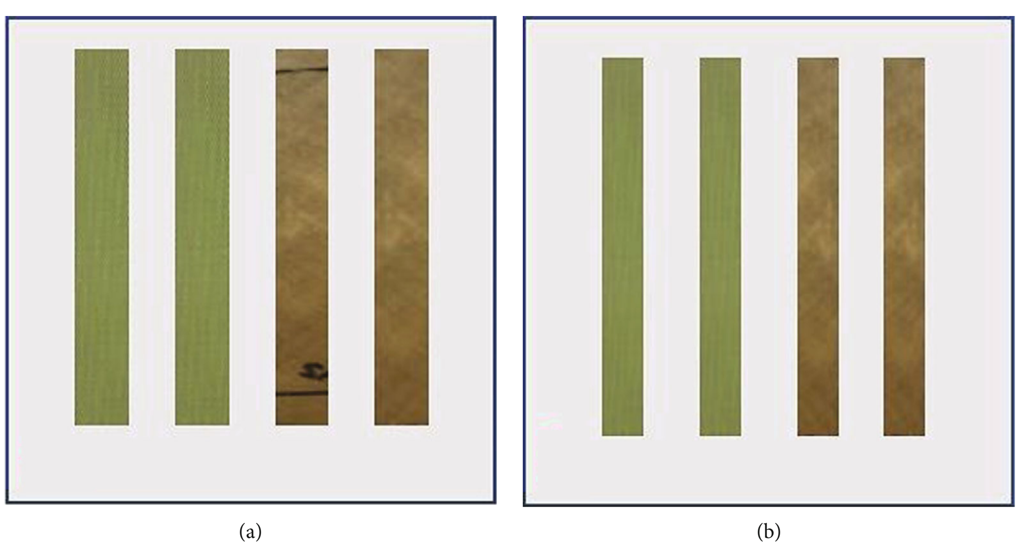
3. Outcomes of Composites

3.1. Mechanical Performance of Filler-Free Mixtures. The tensile behavior and modulus of blank hemp/kevlar hybrid composites and plain epoxy are shown in Figures 5(a) and 5(b). As per the observations, the tensile behavior of the composite mixture was considered to be the most effective in specimen B than in plain epoxy (A) as well as in other hybridization laminate materials (C and D). The mechanical properties of composites using kevlar in the external layer were discovered superior to those of other biocomposites. Compared to kevlar fibers, hemp fibers become less robust, stronger, and have less interfacial shear resistance. When compared to hemp fiber, it has a better load-bearing capacity. As a result, when loaded, it does not easily break. The tensile strength of hemp and kevlar-infused epoxy has grown to 41.5% in specimen 3, 38% in specimen 4, and 48% in specimen B compared with pure epoxy (A). The analysis also reveals that the outer layer contains hemp fiber, which is weaker than kevlar. This might be owing to the larger content of lignin and hemicellulose concentration of hemp fiber, which does not create a strong bond with the matrix. Consequently, it cannot bear the stress and breaks easily when exposed to it. As an outcome of a filament breaking and debonding, the composite's tensile value has dropped [15].

Figures 6(a) and 6(b) compare the bending behavior and modulus of hemp/kevlar mixtures with pure epoxy. The results

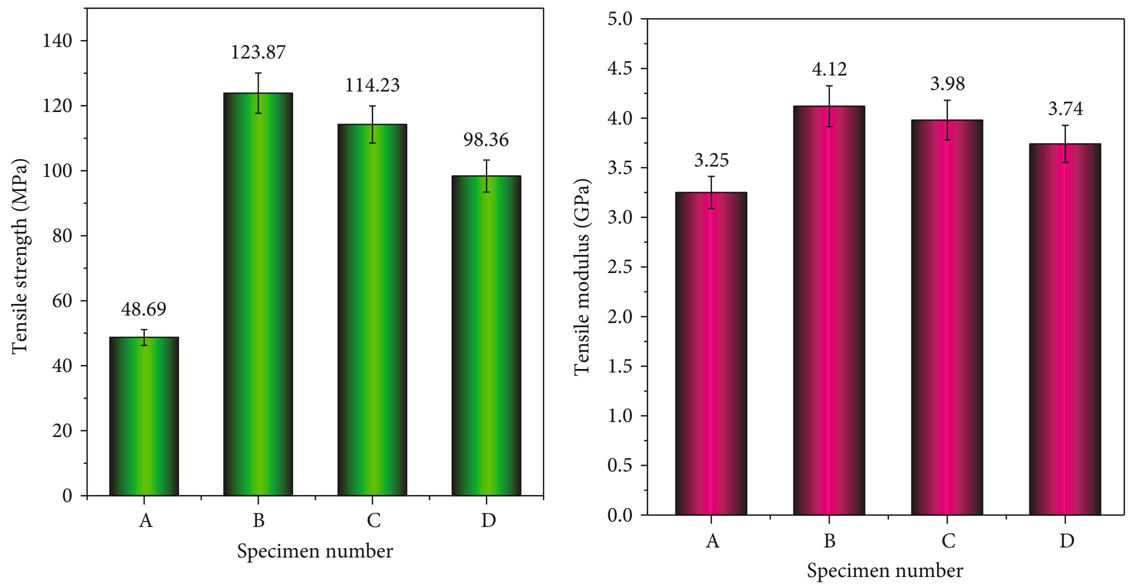
(a) (b) (c)

Figure 3: Fabrication of bio-based nanocomposites by using the hand layup method: (a) applying wax, (b) placing the woven mat, and (c) closing the mould.



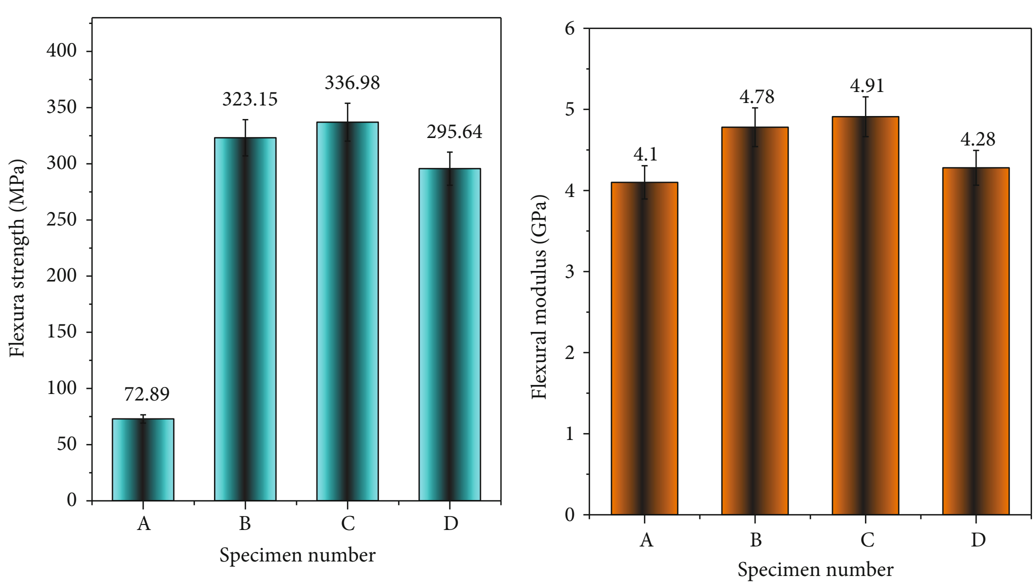
(a) (b)

Figure 4: Photographic images of (a) tensile and (b) flexural specimens.



(a) (b)

Figure 5: Kevlar and hemp-based hybrid composites: (a) tension behavior and (b) tension modulus.



(a) (b)

Figure 6: Kevlar and hemp-based hybrid composites: (a) flexural strength and (b) flexural modulus.

demonstrate that the flexural properties of the hybrid composite are better in specimen C than in plain epoxy (A) and other hybrid laminated composites (B and D). Specimens B and C are nearly equal in terms of strength. Compared to pure epoxy (A), specimen C has an 82% strength, specimen D has a 73% strength, and specimen B has a 79.2% strength. Specimen B is stronger than specimen C, that may be due to the mostly intact contact between polymers and the fibers and to flexing load transfer from the matrix to the kevlar fiber, which could pick up the slack during load conditions. The improvement in toughness is mostly due to fiber hybridization, but at the same time, it depends on piling order; in 3 unique stacking orders, kevlar as the outer layer yields relatively good mechanical behavior. Salman et al. [16] discovered that hybrid composites with kevlar as the exterior surface and kenaf as the inner layer had higher hardness, better energy absorption, and a higher total pile with their research.

3.2. Tensile Behavior of SiO_2-Based Mixtures. Figure 7 demonstrates the tensile behavior of hybrid composites for various piling patterns and varying weight percent of nanosilica. Because of the greater nanosilica distribution that leads to

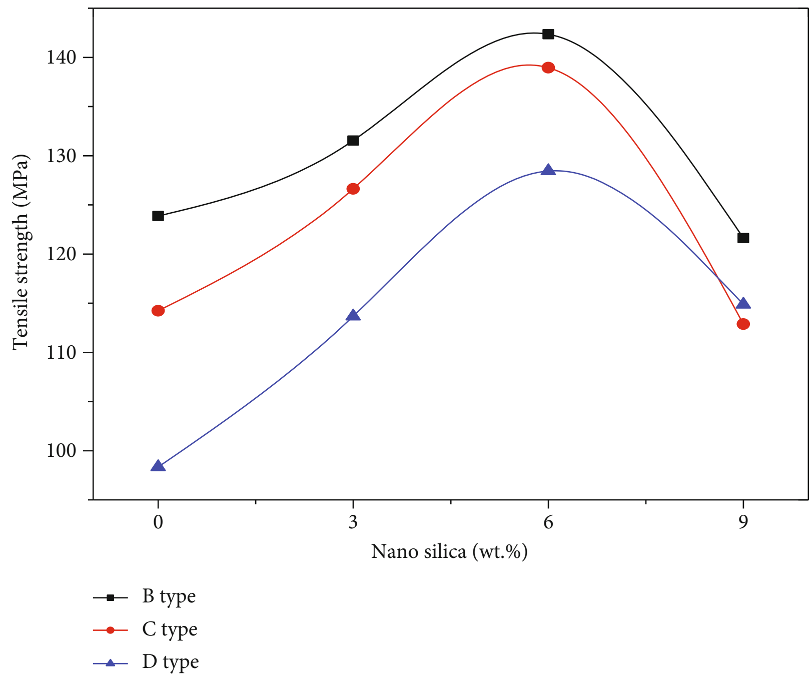


Figure 7: Tensile strength of nanocomposites based on the wt.% of nanosilica.

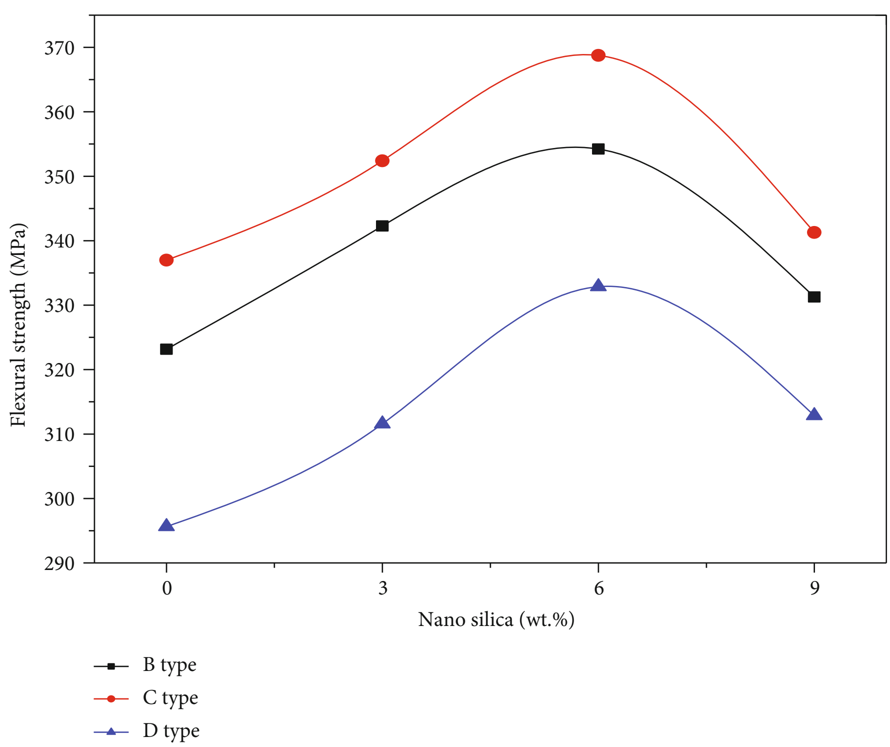


Figure 8: Flexural strength of nanocomposites based on the wt.% of nanosilica.

good interfacial contact with the matrices, the SiO_2 through the dual-mixing procedure increased the tension behavior of the epoxy/hemp/kevlar materials. The tensile strength varies depending on the stacking order. Also, when the proportions of SiO_2 in the material increase, the tensile strength increases and then drops as the amount of nanosilica in the secular declines. A significant correlation was made by Ary Subagia et al. [17]. The tension behavior of SiO_2-based hybrid composites increases with the weight % of SiO_2 from 0 to 6 wt.% and decreases with a further rise in SiO_2 proportions, i.e., 9 wt.%.

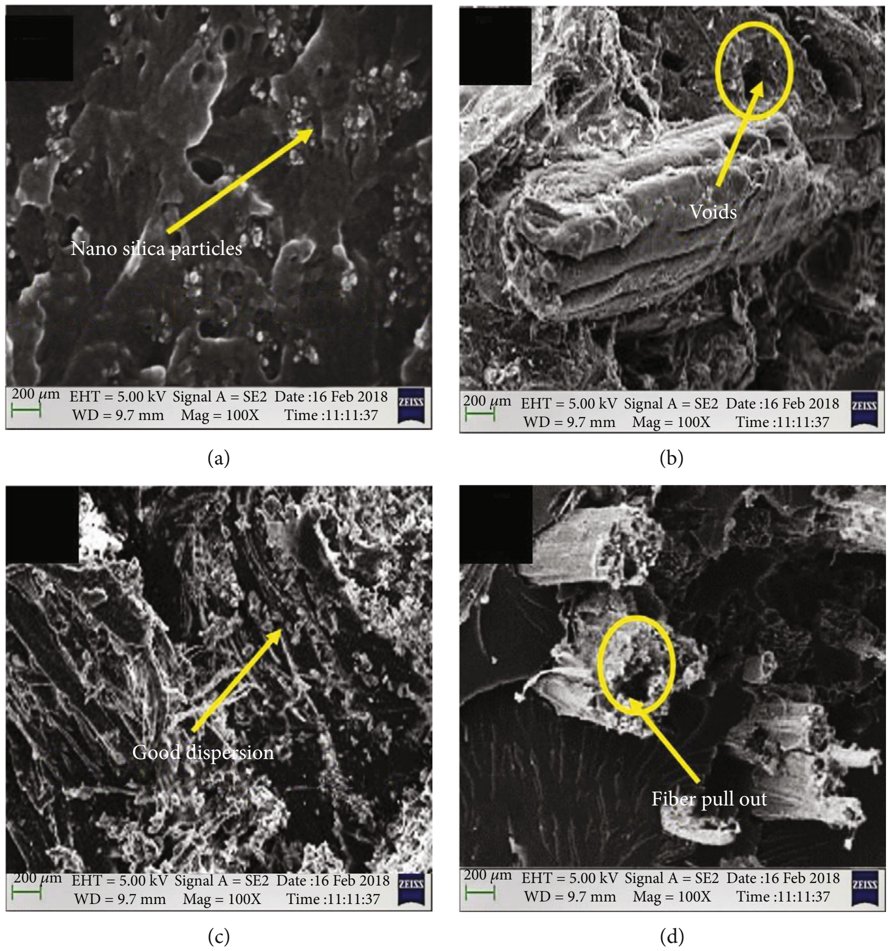


Figure 9: (a)–(d) Microstructural images of bio-based nanocomposites.

This is because aggregation, caused by inadequate nanomaterial dispersion, may lead to inhomogeneity and, eventually, uncured epoxy regions while supplying energy to the blending process. In their research, Singh and Aggarwal et al. [18] found that adding a small quantity of nanosilica to a polymer improved its tensile capabilities. Higher nanosilica concentrations, on the other hand, may exacerbate these tensile qualities. The maximum tensile strength is attained at 6 wt.%, nanosilica/B type stacking sequences would be raised by 25%, and the tensile strength is reduced when the silica content is increased further. This is due to the viscidness of the polymers growing as the weightiness of silica is raised [19]. Any of the stacking sequences will show this outcome. The inclusion of 6 wt.% SiO_2 reduced absorbencies, and the lowered absorbency greatly boosted the resistivity of the nanocomposites. The increased levels of nanosilica induced aggregation and poor distribution, indicating an increase in permeability.

3.3. Flexural Behavior of SiO_2-Based Mixtures. Figure 8 depicts the bending behavior for various piling orders and nano-SiO_2 weight percent. The maximum flexural strength was achieved at 6% of the SiO2/C type piling order. There is an increase in elastic modulus of up to 4% and an additional rise in nanosilica proportion; nevertheless, this is a drop-in bending behavior. Merah and Mohamed [20] found the same tendency in bending behavior for filler content. When 6 wt.% nanosilica is added to C-type composites, the flexural strength increases by 9%, compared to 38% for 3 wt.% and 6 wt.% and 21% for 9 wt.%. From 0 wt.% to 6 wt.%, the bending strength of the C-type stacking sequence has increased by 38%. The aggregation of SiO_2 in the epoxy, which acts as a stress concentration and reduces bending behavior, may cause the loss in flexural behavior of more than 6 wt.% SiO_2.

3.4. Microstructural Analysis. Figure 9 shows 20 μm and 50 μm magnification SEM images of the B-type stacking process with 0 wt.%, 3 wt.%, 6 wt.%, and 9 wt.% nanosilica. The presence of voids in the composites can be observed in the image, indicating no interfacial connection IN between the reinforcements and matrices. Figure 9(a) indicates the dispersion of silica particles in the plain epoxy resin. SEM images of confirmed bending samples of epoxy/C type stacking sequence hybrid composite and epoxy/C type stacking specimen/nanosilica composite with 6 wt.% nanosilica are shown in Figures 9(b) and 9(c). There is a clear difference between the specimens with and without nanosilica. In all the considered samples, fiber withdrawal can be noticeable. The flimsiness of the hemp fiber may be perceived now. The effects of adding fillers to hybrid composites are shown in Figure 9(c).

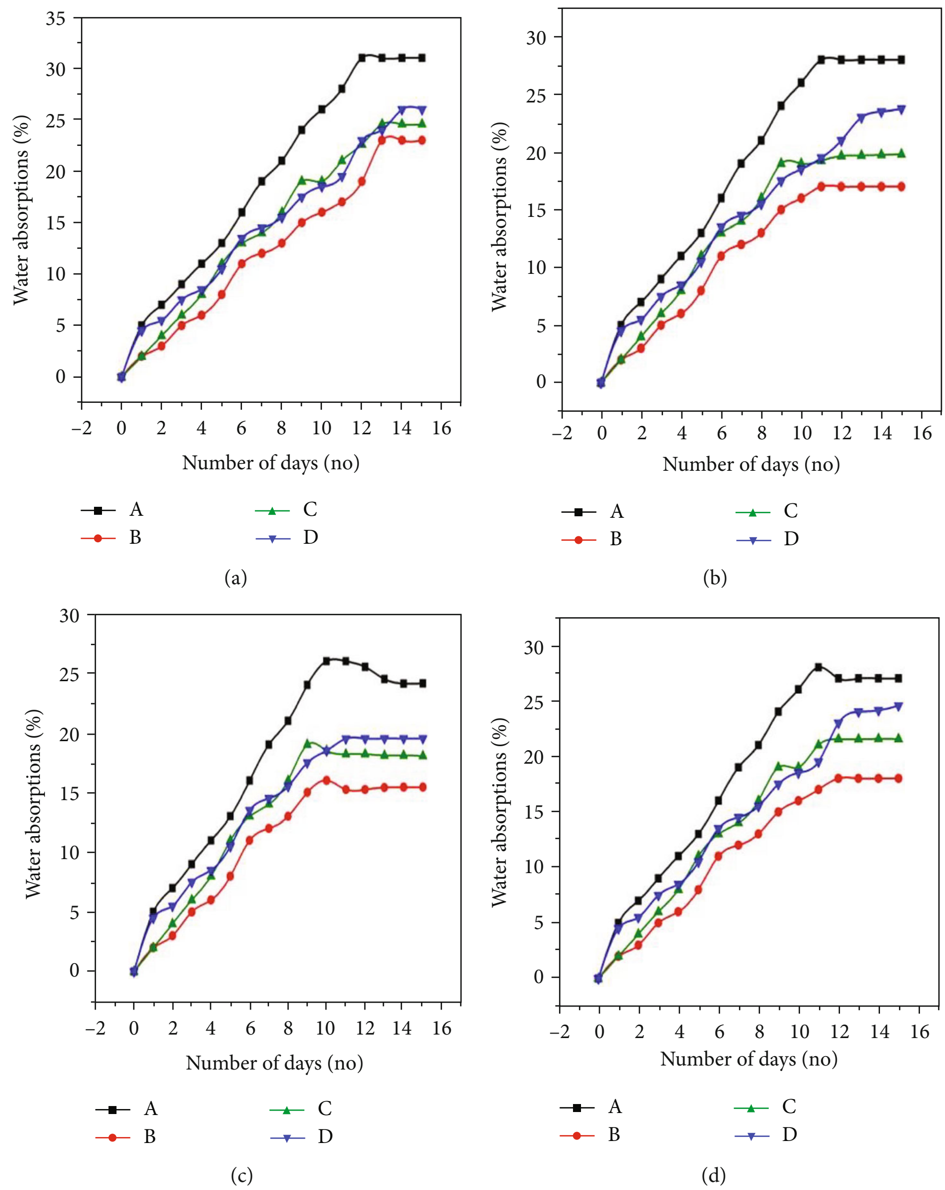


Figure 10: Hygroscopic behavior: (a) 0 wt.% of silica, (b) 3 wt.% pf silica; (c) 6 wt.% of silica, and (d) 9 wt.% of Silica.

Due to flexural load, the fracture development before breaking is seen to be lower than in Figure 9(b). This demonstrates that the fillers improve the strength of the composite which shows that the composites have no void and that the presence of nanosilica has resulted in a strong interfacial connection between the reinforcement and resin. It depicts the composite's homogeneous particle dispersion. Due to the ultrasonic mixture of nano-SiO_2, less absorbency could be seen in the pictures, which are comparable to those of Madhukar et al. [21]. The kind of fiber, matrix, matrices and their reinforcement connection, fibers transmission area of breakage, and other factors influences composite failure mode [22]. Furthermore, adding the silica weight % resulted in a negative outcome, indicating a reduction in mechanical strength [23]. This indicates the poor boundary adherence of fiber and matrix [24], resulting in aggregation due to poor adhesion and inferior composite strength qualities [25]. It is demonstrated in SEM image Figure 9(d).

4. Effect of Nanofiller on Moisture Preoccupation Characteristics

Hygroscopic characteristics of composites with different layering sequences are shown in Figure 10. Figures 10(a)–10(d) demonstrate the hygroscopic behavior of nanocomposites in the addition of 0 wt.%, 3 wt.%, 6 wt.%, and 9 wt.% of silica powder. At the beginning, the rate of water updating for all composite materials was high [26], but this level has become almost consistent and reduced in the end phase [27]. According to the findings, all the composite materials exhibit a high moisture uptake rate with the increased time durations [28]. After the first day, moisture content ranged from 7 to 14%, climbing to 17–33% for various composites [29]. It has been shown that the proportion of filler particle concentration considerably influences the parameters of the composite's water uptake [30]. According to Subsection 4, an A model sample exhibits the biggest water retention. The wetness acquisition may be affected by increasing the concentration of nanofillers (3, 6, and 9 wt.%), as illustrated in Figure 10 [31]. When the filler level is higher by up to 6%, the water retention drops and the hygroscopic rises [32]. The result of excessive nanoparticles in the matrices is a mixture that raises the mixture's stickiness [33] and causes poor insemination of a combination (matrix-filler) into the fibers [34]. There is poor moisture between the fiber matrix and the laminate with voids from insufficient insemination [35], which will absorb more water [36]. For the majority of composites, the rates of water uptake are greater at 0% filler loading (steeper gradient of water uptake proportion and immersed duration chart) [37]. As a result, compared to those other filler substances [38], they can achieve saturation water content with a shorter soaking time [39]. In comparison to a composite without filler, the use of filler lowers the composite's water retention rate and increases its stability in sticky situations [40].

5. Conclusion

The mechanical characteristics of the hemp/kevlar/nanosilica-reinforced epoxy-based hybrid nanocomposites were evaluated according to ASTM standards using the hand layup procedure. The following are some observations:

(i) Due to the ultrasonic swirling procedure in the production of composites that aids in the appropriate dispersal of nano-SiO_2 in hybrid mixtures, mechanical characteristics are dramatically improved with nanosilica inclusion

(ii) The composites, type B specimen, 6 wt. percent nanosilica and type C specimen/6 wt. percent nanosilica composites, had the maximum tensile and flexural strength. It promotes strong bonds between nanofillers and the matrix. Due to incorrect soaking of the fillers and difficulties in fiber/filler interaction, the mechanical characteristics of hybrid composites are diminished after 6 wt.% filler addition

(iii) Hybrid composites (type C) have a 38% increase in flexural strength and a 25% increase in tensile strength due to using 6 wt.% fillers and a two-step swirling procedure in the production of composites

(iv) According to SEM measurements, the ultrasonic stirring procedure results in the appropriate dispersal of fibers in the hybrid mixtures. The results show that nanosilica particles have high adhesive strength and chemical compatibility with epoxy, hemp, and kevlar biocomposites

(v) Compared to A, C, and D type model composites, B type model composites with a 6 wt.% addition of nanosilica exhibit better hygroscopic behavior. Furthermore, adding the silica weight percent also resulted in a negative outcome. This indicates the poor boundary adherence of fiber and matrix, resulting in aggregation due to poor adhesion and inferior composite strength qualities

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

Acknowledgments

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