Hindawi
Journal of Nanomaterials
Volume 2022, Article ID 4971582, 9 pages
https://doi.org/10.1155/2022/4971582

Research Article

Flax- and Graphene-Reinforced Natural Fiber Nanocomposites under Cryogenic Environment for Constructional Applications

Munirah D. Albaqami,[1] N. Krishnamoorthy,[2] S. D. Uma Mageswari,[3] Sarita Santaji Shinde,[4] S. C. V. Ramana Murty Naidu,[5] Neha Munjal,[6] Aboud Ahmed Awadh Bahajjaj,[1] S. H. Mohammed,[7] and Prasath Srinivasan[8]

[1]*Department of Chemistry, Sree Krishna College of Engineering, Vellore, 632101 Tamil Nadu, India*
[2]*Department of Physics, Sri Eshwar College of Engineering, Coimbatore, Tamil Nadu 641202, India*
[3]*Department of Science and Humanities, R.M.K. Engineering College, Kavaraipettai, Tamil Nadu 601206, India*
[4]*Department of General Science, Bharati Vidyapeeth's College of Engineering, Kolhapur, Maharashtra 416013, India*
[5]*Department of Mechanical Engineering, Sri Venkateswara College of Engineering & Technology, Srikakulam, Andhra Pradesh 532410, India*
[6]*Department of Physics, Lovely Professional University, Phagwara, Punjab 144411, India*
[7]*Department of Mechanical Engineering, C. Abdul Hakeem College of Engineering & Technology, Melvisharam, 632509 Vellore, Tamil Nadu, India*
[8]*Department of Mechanical Engineering, College of Engineering and Technology, Mizan Tepi University, Ethiopia*

Correspondence should be addressed to Prasath Srinivasan; prasathsrinivasan@mtu.edu.et

Received 11 May 2022; Revised 26 June 2022; Accepted 30 June 2022; Published 3 October 2022

Academic Editor: Arpita Roy

Copyright © 2022 Munirah D. Albaqami et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Mostly at the micro- and nanoscales, efforts were made to produce innovative thermoplastic nanocomposite materials. These composites were reinforced with natural fibres and artificial additives with improved mechanical characteristics. This research entails the creation of a novel nanocomposite material made up of unsaturated polyester resin, graphite at the nanoscale, and flax fibres at the microscale. Flax fibres make up 4, 8, and 12% of the binding matrix's weight, respectively. A constant quantity of nanoparticles equal to 4 wt% of the binding matrix is used. In order to stick the graphene to natural fibres, an appropriate surface alteration approach is needed, and this work will focus on the plasma technique of interface adherence. Fibres were employed as a reinforcement with polyester to create a nanocomposite that improved adherence between the fillers while also retaining the matrix alkalisation. In order to assess interferential adherence and fibre distribution homogeneity in the matrix system, the composite was made up of hand lay-up technique. The manufactured composite was engrossed into fluid N_2 at -196°C. A SEM was utilized to undertake treated and untreated specimens for spectroscopy analyses. Mechanical possessions like tension and flexural were accomplished. In comparison to previous tested doses, the 5 percent alkali-treated flax incorporating graphite has shown promising outcomes than other samples.

1. Introduction

Awareness of environmental issues and social response is raised, as improved pollution regulations and inefficient oil consumption, prompting consideration of ecofriendly products. Organic fibre is one of the most ecologically compost resources on the market, exceeding man-made materials in a number of ways. As per a recent industry assessment, the global market for organic fibre-based material is expected to reach $3.9 billion by 2023. The global trend in the NFPC industry, as per current estimates, will continue to develop fast [1]. A natural fibre-based polymer composite has become increasingly popular in consumer goods and the rising industrial sectors in recent years. The NFPC industry is expected to increase by 12% worldwide during the next five years (2021–2025), as per forecasts [2, 3]. Natural fibres are nonsynthetic, non-man-made fibres. Animals and plants can both provide them. Natural fibres derived from both sustainable and nonrenewable substances, like groundnut, jute, hemp, and cotton, have gotten a lot of consideration in recent decades. Bast fibres, namely, kenaf, hemp, ramie, flax, and jute as well as all other forms of cellulose fibres, can be classified as "roots and wood." Fibre-reinforced polymer matrices are extremely lightweight, low cost, and less damaging to processing equipment and have relatively high mechanical properties, so they are used in numerous submissions owing to the better strength and advantages of organic fibres over man-made fibres. It is getting a lot of attention. Flexural strength and tensile strength enhanced surface polish of moulding composites, plentiful recycling, and flexibility at assured individual facilities, renewability, and stumpy interface risks. Plant fibres and particles, both tough and gentle, are added to the polymeric materials [4, 5]. Figure 1 demonstrates the composites with different applications.

Flax appears to be the only major species in the Linaceae class, which has twelve divisions and around 350 names. Flax was still the first fabric produced of grains and subsequently strengthened into mixtures that was recovered in Egyptian burials about 5000 B.C. It is among the most often used biofibres. Flax has been farmed for decades for fabric and lubricants, and it is a main ingredient [6]. Flax is the target of intensive study as well as the incorporation of desired features like herbicide endurance, organic and inorganic antioxidant enzyme activity, and better oils and protein categories. Linseed is a 0.5-2.9 m in height annual herb having branches measuring 11-30 mm [7]. Low density, strong elastic modulus, flexibility, and a high surface to volume ratio characterise such ligno fibres. Flax fibre's mechanical characteristics are determined by its location in the stems. Enhance the loading level from 2.40% per minute to 8% per minute to raise interfaces shear capacity by few more % with no effect in the composite's overall strength properties. Even though natural fibre-based composites are not without flaws, they remain a viable option. Since natural fibres have a lower water barrier, they absorb a lot of water and have poor mechanical properties [8]. Figure 2 displays the compensations and drawbacks of dissimilar fibres.

Several additives are contained in the same lattice to produce hybrid composites. By removing the disadvantages of individual aggregates, combination improves the material properties of natural composites [9, 10]. Therefore, the impact of blending fibres in grids has outlived its usefulness in terms of increasing biomechanical qualities. The nanofibres are used to improve the bond between the matrix and reinforcements, significantly increasing the properties. As a result, the use of nanoparticles in thermoplastics is becoming increasingly prevalent. Due to their subatomic scale, nanocrystals have features that can still be utilized to build new items or improve the efficacy of structural members [11]. The nanosized particles have a variety of uses in water purification, energy generation, and contamination detection, and a substantial proportion of research discusses how innovative nanoparticles might be employed to solve key environmental issues. Graphene is a single dioxide film of molecules organised in a hexagon crystalline substance, which is the most recent substance to catch scientists' interest [12, 13]. The remarkable physicochemical features of graphene, particularly its extremely large surface region, electron and thermal movement, and good mechanical, have piqued curiosity. These remarkable qualities comprise prompted substantial efforts to integrate graphene into a wide range of technological applications, from electronic systems to biomaterials. As well as nanomaterials and polymer composite components have been seen in the identification of innovative activated carbon or photocatalytic activity machinery for economical decontamination, as key components for another water filtration substrate and also as electrocatalyst for particulate traceability or eviction in the area of natural engineering [14–16]. Different chemical treatment procedures can increase the adhesion among unsaturated polyester resin and flax fibre. Thermal comfort may be made from bast fibres such as flax. The elastic modulus of flax fibres was discovered to be influenced by the size and orientation of a tensile strength after evaluating them during loading condition and repetitive packing trials. The formation of coherence interfacial adhesion between both the fibre and matrix improves the fibre-reinforced nanocomposite substance's effectiveness. Surface modification of the nanocomposites, on the other hand, causes undesired consequences like mechanical deterioration, renegotiation by severe swell, and exterior deterioration [17, 18]. Polymers being used in industrial applications, for instance, would have to be able to endure temperatures of up to 200 degrees Celsius. Microstructural minerals and plastics have the highest rigidity, are much more resilient, and have greater strength and durability. As a result, freezing processing of composites could be a key component of revolutionary goods to increase the quality of organic lignocellulosic fibres [4, 10, 19, 20]. The foremost persistence of this study is to develop and evaluate hybridised organic nanostructures for material characteristics. The graphite and flax fibre fabric hybrids were made by hand. The material properties of the fabricated samples were evaluated following different durations of immersion in aqueous nitrogen at 77 K.

2. Investigational Resources and Methods

2.1. Flax Fiber. Flaxseed that has not been treated is being used in the study. Flaxseed strands have such superior mechanical properties and may be easily extended when damaged. The relative humidity is roughly 11%. The molecular structure seems to have a considerable influence on the properties of the filaments and the properties of the material as a result. Strands were chopped to a 5 mm length in order to be used with textile trimming machinery. The flaxseed strands were supplied by the Ganga fibre factory in Salem, Tamil Nadu, India. Figure 3 illustrates the flax fibre and matrix materials.

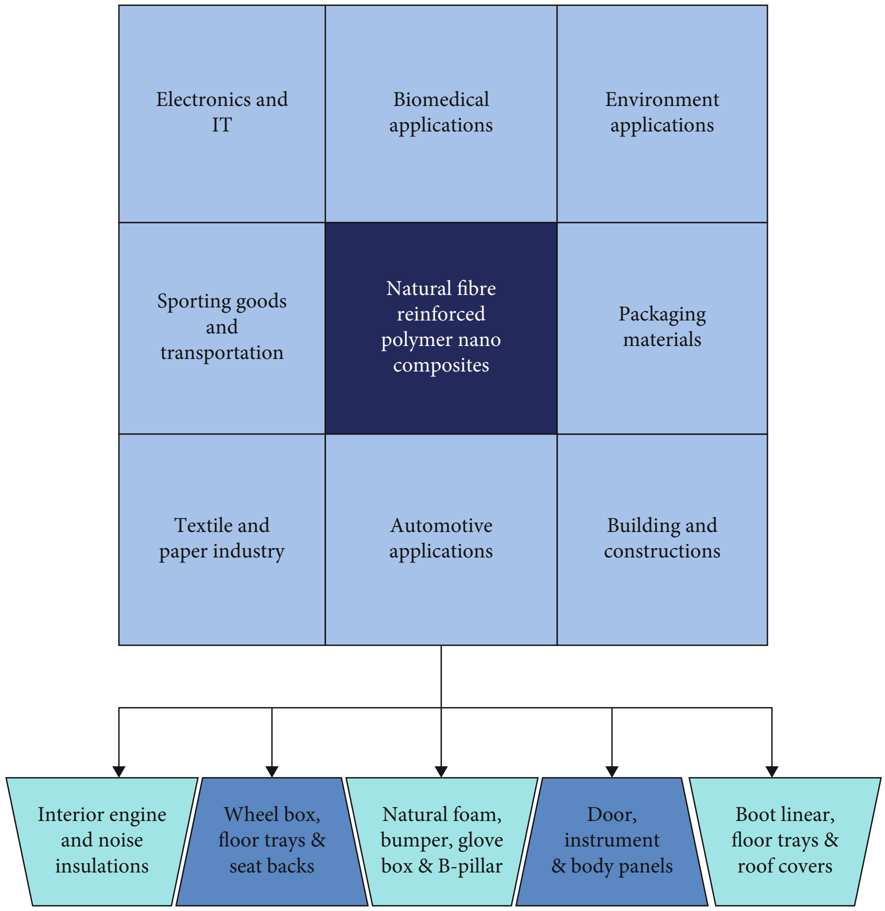


Figure 1: The composites with different applications.

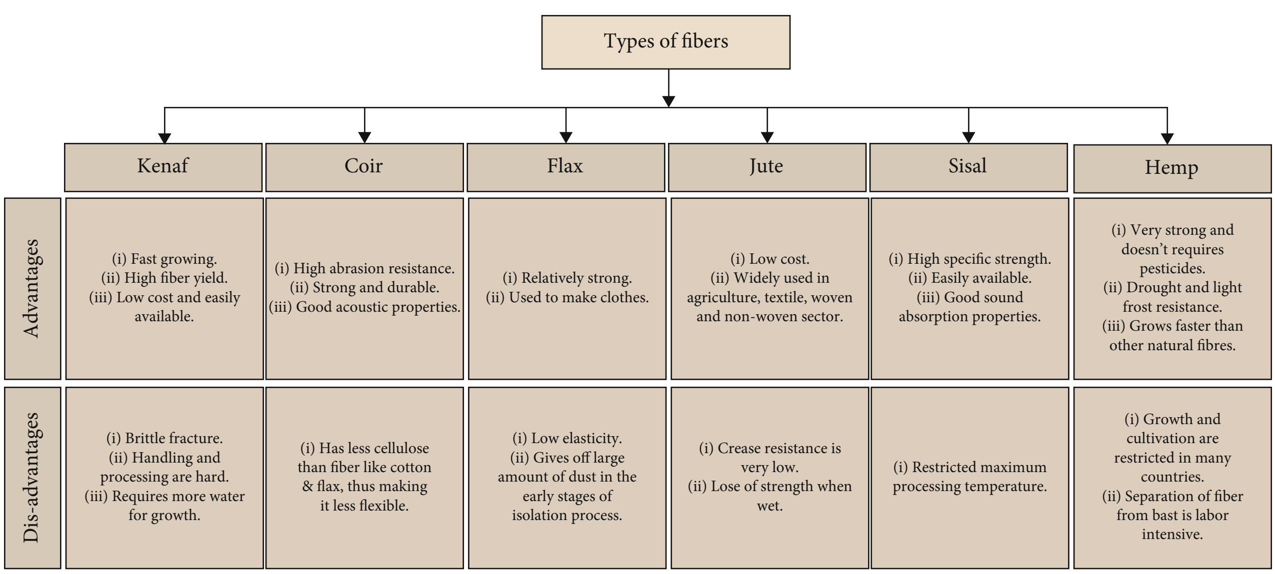


Figure 2: The advantages and disadvantages of different materials.

2.2. Nanofiller. The graphite employed by the researcher has been of protective coating, with a purity of 90%. To create different nanomaterials, different amounts of 0.1-6 percent of the polymer matrices were used in sequential increments of 1 percent by weight of the polymer matrices. Figure 4(a) depicts the graphite material used in this experiment. The

(a) (b)

Figure 3: Photographic images of flax fibre and matrix materials.

graphite used in this study was black in colour with a known quantity of 11.25 g/mol and an iron concentration of ≤100 ppm.

2.3. NaOH Dispensation. One of the really common treatments on plant fabrics used for lightweight materials is alkaline hydrolysis. Surface modification disrupts hydrogens on the intermediate scaffolding, resulting in improved load bearing capacity. The quantity of tannins, a lipid that covers the majority of the external skin of flaxseed, is decreased to a considerable extent. Also, it aids in cellulose isomerization and the exposure of lengthier allotropes.

For this type of dehalogenation, fresh flax was obtained and carefully washed. As a consequence, the flaxseed was carefully chopped into lengths ranging from 5 to 8 mm. According to the study, the linseed strand was then soaked in a 10% NaOH solution at maximum strength for four hours. After that, liquid-converted linseed was dampened using methanol until its pH neared 7, as determined by fluorophore. To eliminate any surplus ingredients, the combined material was carefully strained using deionized water. It would bring the acidic process to a close.

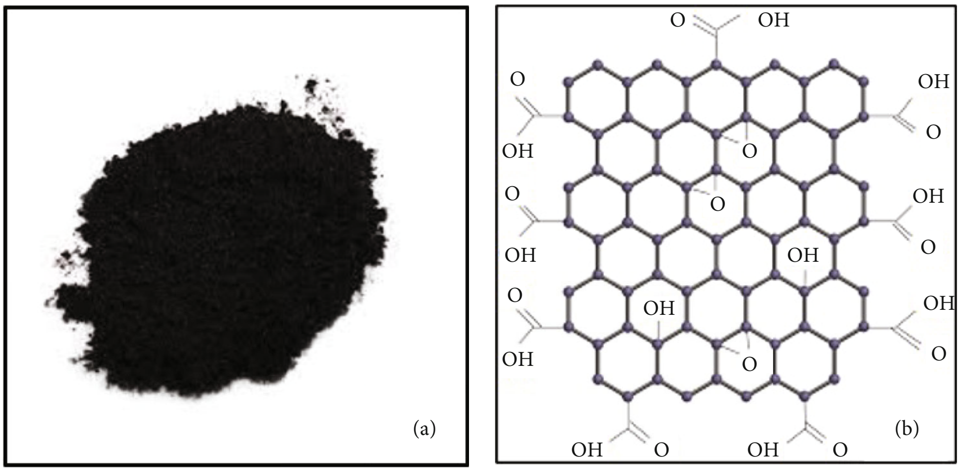
2.4. Fabrication of Hybrid Composites. The graphite employed by the researcher has been of protective coating, with a purity of 90%. To create different nanomaterials, different amounts of 0.1-6 percent of the polymer matrices were used in sequential increments of 1 percent by weight of the polymer matrices. The ultrasonic irradiation procedure was applied to distribute graphite with flaxseed in synthetic materials. Furthermore, to distribute the graphite and flax, multiple sheared mixing techniques have been used, as well as continually mixing the mixture. Such motorised mixing is done for a set amount of time till the combination is homogeneous. During motorised churning, gases are maintained but must be removed using a related discipline technique. The mixture is cured for two hours at 650°C, followed by three hours at 1050°C. The resins and cure chemical combinations were poured into a 300 mm × 300 mm × 3 mm aluminium mould to manufacture biocomposites. Table 1 shows how the nanocomposite manufacturing were made depending also on limitation categories. Following that, the produced specimens were flooded in liquid N_2 at 77 K for cryogenic treatment for various times according to the specification. The treated plates were detached from the cryogenic compartment and maintained normal temperature.

2.5. Testing of Composite Specimen. As shown in Figure 5, the laminating specimens were extracted to ASTM D 638-03 models for uniaxial tensile testing and ASTM D 790 models for bending testing.

2.6. Scanning Electron Microscope (SEM). SEM was used to do microinspections of fractured lamination testing. To increase the ionic characteristics of the mixes, all materials were laved, dehydrated, and afterwards mechanically coated with nanometres of gold throughout SEM magnification.

3. Result and Discussion

3.1. Tensile Strength. The mean tensile changes of a flax-/graphene-reinforced hybrid composites with fibre weights of 4%, 8%, and 12% were evaluated based on the varied fibre loadings. Figures 6(a) and 6(b) show the bar and area plot of ductile properties. The tensile strength of the composite improves with the addition of flax fibre content till it reaches 8% and then drops to 12%. When compared to a 12 percent fibre-reinforced composites, the inclusion of 3 percent graphene and 8% boosts the tensile strength of the nanocomposites. The poor transfer of stress owing to the maldistribution of fibre all across the matrices is the cause of low durability in 12 percent fibre composites. In the final outcome, the compound formed a polymer high area with weak fibre-to-fibre and fibre-to-graphene contact. The fibres were effortlessly pulled from the resin at loading in current state. It demonstrates that the fibre/graphene hybrid's 12 percent strengthening consequence is inadequate to tolerate the tensile force. The fourth sample (eight percent flax fibre and three percent graphene-reinforced composite) has an extreme ductile value of 48.96 MPa, which really is 10.75 percent greater than the fifth specimen. This is primarily attributable to the establishment of crosslink density between fibre matrices, which occurs as a consequence of the fibres filling in the voids in the composites by admitting extra fibre, thus providing sufficient force distribution across clusters [14, 21].



(a) (b)

Figure 4: (a) Photographic image of graphene powder. (b) Biochemical assembly of filler.

Table 1: Combination levels of nanocomposites.

Specimen	Combinations	Treatment
Specimen 1	Polyester+graphene	Untreated
Specimen 2	Polyester+flax	Untreated
Specimen 3	Polyester+4% flax+3% of graphene	3% and 5% of NaOH
Specimen 4	Polyester+8% flax+3% of graphene	3% and 5% of NaOH
Specimen 5	Polyester+12% flax+3% of graphene	3% and 5% of NaOH

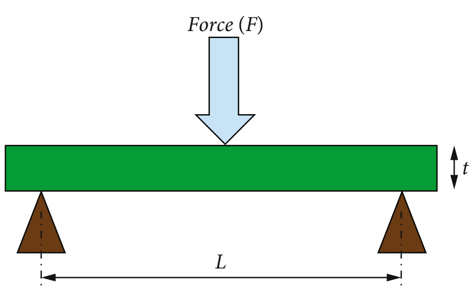


Figure 5: Schematic image of flexural testing.

3.2. Flexural Strength. The bending strength of flax/graphene/polyester hybrid composites varied as shown in Figures 7(a) and 7(b). When the fibre content of the hybrids is raised until it reaches 8%, the flexural strength increases until it drops to 12%. When the fibre loading of the composites is increased, the flexural strength value consistently increases. In 8% of the fibre content of the nanocomposite, the highest flexural strength was achieved. The yield of a 4 percent flax with 3 percent graphene sample is 21.78 percent greater than the yield of a 12 percent flax with 3 percent graphene specimen. Furthermore, the percentage of flax with 3 percent graphene is 4.65 percent greater than the percentage of flax with 3 percent graphene specimen in the 12 percent of flax with 3 percent graphene specimen. In all situations, the flexural strength of the fourth specimen is greater than other specimens. Flax fibres are haphazardly put without appropriate orientation, producing unequal fibre distribution, which is the main source of this disparity. The composite was unable to endure the flexural strength as a result of this. The higher percentage of fibre content could achieve adequate crosslinking density and poor hydrophilicity between fibre and matrix at 12% hybrid, while the needed percent of fibre loading can achieve adequate bonding strength at 8 percent specimen. The 8 percent flax fibre with 3 percent graphene composite exhibits strong bonding, allowing the reinforcement to distribute stress evenly all across the matrices [6, 22].

3.3. Effect of NaOH Treatment. The alkali or NaOH procedure was used to change the morphology of flax fibre's interface. Figures 8(a) and 8(b) show the effect of NaOH treatment on tensile and flexural strength. The impact of NaOH processing on the tensile and flexural characteristics of flax-/graphene-derived nanocomposite is shown in the figure. The mechanical characteristics of the fourth specimen, which contained 8% flax and 3% graphene, were the greatest of the five. The 5 percent NaOH-treated nanocomposite specimens had the best tensile and flexural characteristics when compared to untreated and 3 percent alkali-treated composite specimens. The efficiency of eliminating impurities from the surface of the fibre was not good enough to get through lesser NaOH concentrations, caused by inadequate fibre interaction with matrices. Flax fibres were chemically pretreated for 4 hours with a 5 percent sodium hydroxide (NaOH) solution to remove hydrophilic hydroxyl groups and impurities from cellulose fibre flax. Although

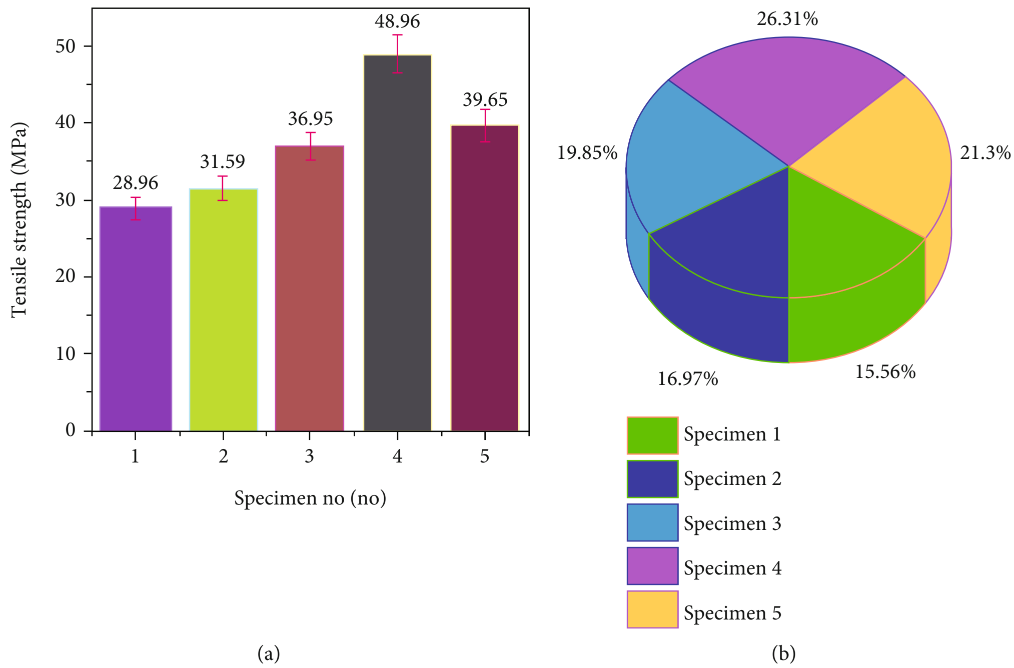


Figure 6: (a) Bar chart and (b) surface plot of tensile strength of nanocomposite.

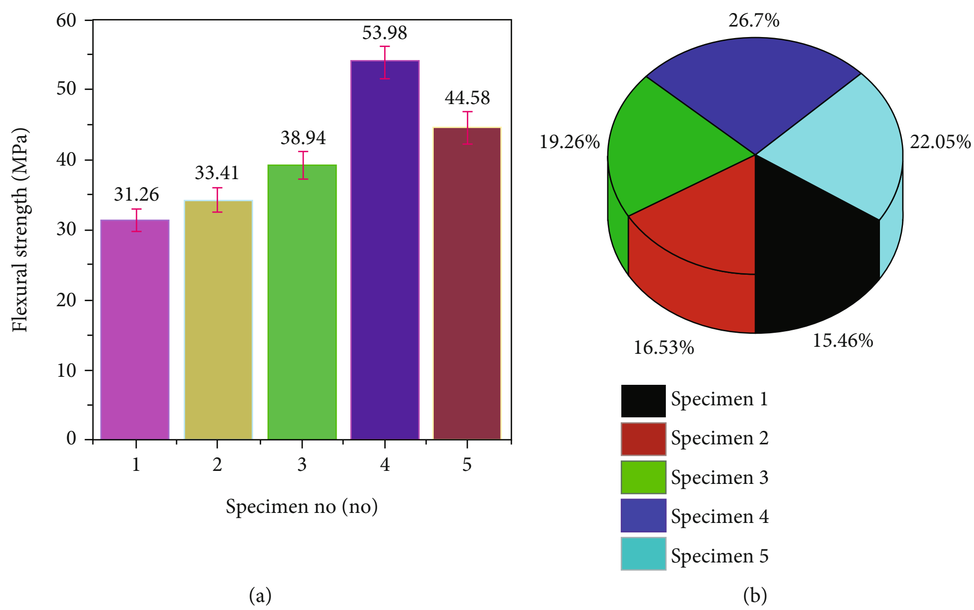


Figure 7: (a) Bar chart and (b) surface plot of flexural strength of nanocomposite.

with the polyester matrix and graphene, this will increase fibre adherence and resilience. This improves the mechanical and morphology characterisation by increasing the levels of a polymerization process as well as the degree of crystallinity of fibres [23].

3.4. Effect of Cryogenic Treatment. In cryogenic fabrication, the nanocomposite pieces were subjected to fluid N_2 at -196°C and went through current treatment. Under cold circumstances, the average values of tensile and flexural behaviour of flax- and graphene-incorporated hybrid materials are revealed in Figure 9. Nanocomposites with 30 minutes cryogenically treated samples had enhanced tensile and flexural strength when compared to untreated samples. It might be owing to the latent stress induced by compression interaction as a consequence of the cold draining of materials. Residual stresses were formed at a low temperature as a result of matrix changes, including fibre contraction. Since fibres have a reduced thermal process of continuous polymeric composites, the resulting stress is compressed as in

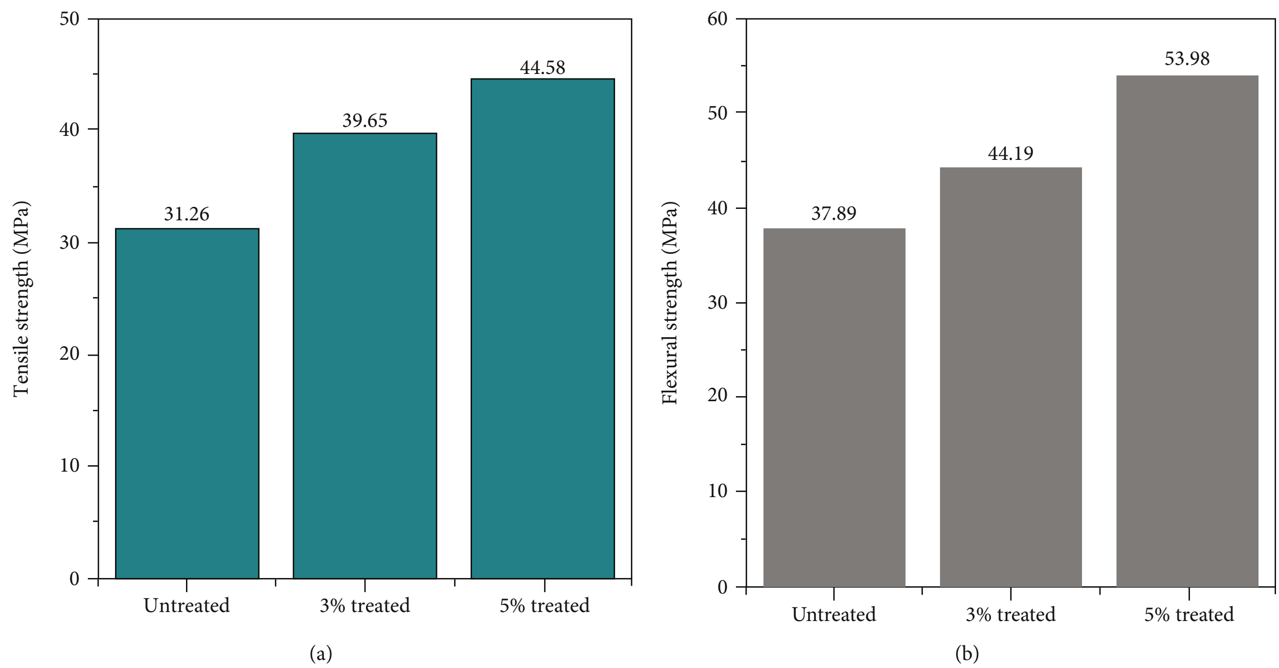


Figure 8: Effect of NaOH treatment on (a) tensile strength and (b) flexural strength.

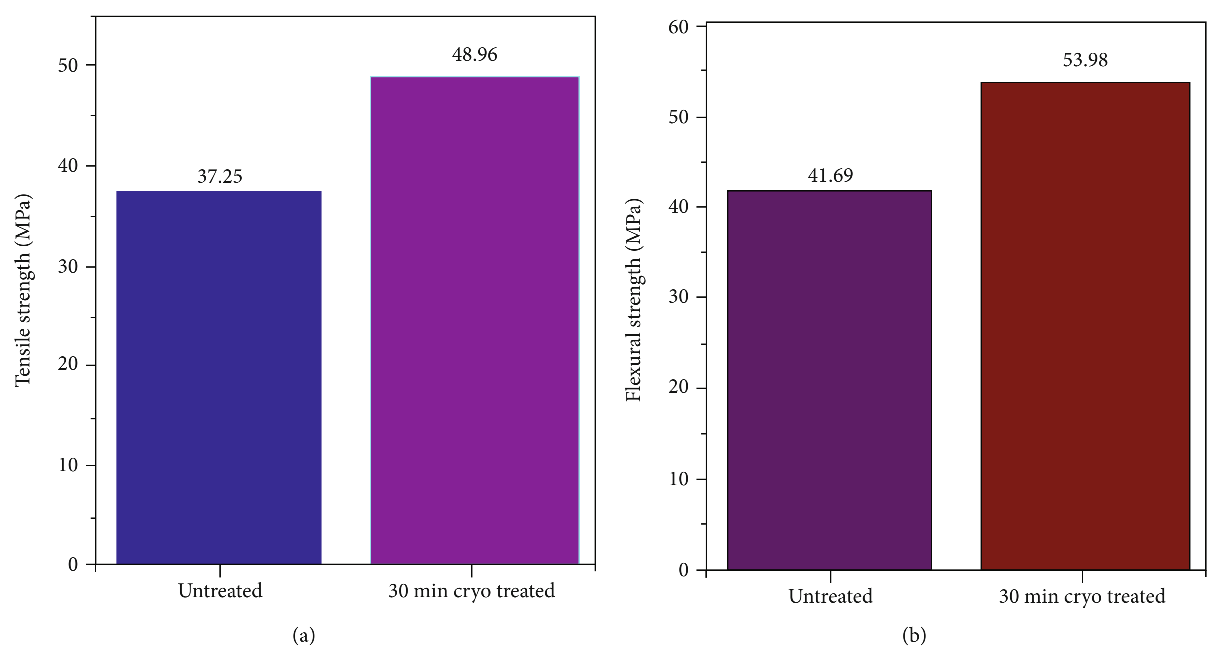
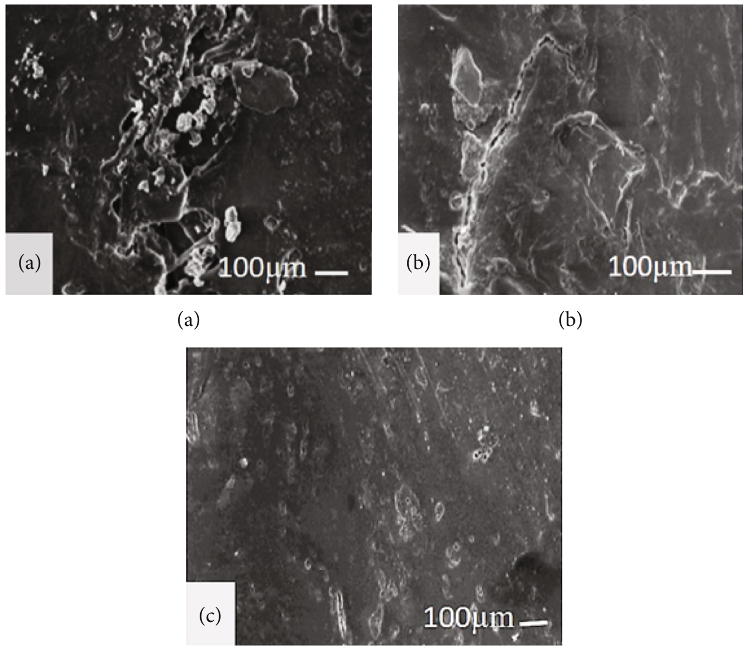


Figure 9: Consequence of cryogenic behaviour on (a) tension behaviour and (b) flexural strength.

thread with strain inside the matrix. Such compressing interlayer pressures help to maintain the fibres and polymers in contact and improve adhesion, which leads to better results. Liquid nitrogen cracking of manufactured composites makes the components more resistant to relatively low temperatures [2, 4, 10]. Figures 9(a) and 9(b) demonstrate the impact of cold working on the physical and mechanical properties of nanomaterials.

3.5. Microstructural Analysis. SEM was employed to investigate the surface morphology of the nanocomposite sample following the transverse tensile test revealed in Figures 10(a)–10(c). The interface of the nanocomposite fails mostly due to inadequate adhesive binding and fibre pull-out for unprocessed flax fibre (Figure 10(a)). Fiber breaking is uneven and happens in the direction of the fibre. The rate of fibre pull-out is reduced, and fibre breaking is



(a) (b) (c)

Figure 10: Microstructural images of (a) untreated, (b) 3% NaOH-treated, and (c) 5% NaOH-treated nanocomposites.

much more uniform with alkali-treated fibres. This shows that the interfacial adhesion between alkali-treated flax fibre and the polyester matrices has improved. Figure 10(b) illustrates a graphene-based flax fibre composite with a changed fracture surface and good resin-fibre binding. Furthermore, the brittle look of the matrix indicates strong interfacial interaction, which can contribute to improved nanocomposite mechanical characteristics. The permeability of the composite materials is next studied by examining the cross section of alkali- and graphene-treated polymers at greater magnification (Figure 10(c)). The interface permeability (lumen permeability and insemination permeability) in 3 percent alkaline-processed fibre composites is depicted in Figure 10(b). Because of the permeability, the composite may break quickly in the direction perpendicular. Figure 10(c) shows that when alkali-treated flax fibres are exposed to 5% alkali, similar permeability is not observable.

4. Conclusion

From the preceding study that natural fibres can be used more effectively in polymeric materials, the following statements were derived from the experimental part.

(i) In a tensile test, the 5% surface treatment increased strength by 33 times and load bearing capability by 8 times when compared to a clean polyester specimen. Natural fibres are treated to improve the matrix's toughness

(ii) We discovered that 3% alkali-processed flax gave more than six times the output of unprocessed flax in mechanical testing. The strength of the structure decreases when the reinforcement is increased

(iii) The improper dispersion of flax and the bonding capabilities of flax with polyester might be the reason of the reduced strength of untreated flax. After a certain chemical treatment, fibres grow harder and bonding becomes easier

(iv) Cellulose depolymerizes, revealing crystallites of short length. As a result, we may conclude that treating flax fibres aids in the attainment of greater strengths

(v) The nanocomposite that has been cryogenically treated for 30 minutes has the maximum mechanical strength. It might be due to the latent tension created by compression contact as a result of nanocomposites' cryogenic straining

(vi) In future, chemical treatment effects like bonding, cracks, fracture toughness, and FTIR can be studied

Data Availability

The statistics often used to support the study's conclusions are supplied in the paper. On request, the associated author can provide more data or information.

Conflicts of Interest

The authors state that the publishing of this paper does not include any conflicts of interest.

Acknowledgments

The authors appreciate the supports from the Mizan Tepi University, Ethiopia, for providing help during the research and preparation of the manuscript. The authors thank the Sree Krishna College of Engineering and C. Abdul Hakeem College of Engineering & Technology for providing assistance to this work.

References

[1] B. Bakri, A. E. E. Putra, A. A. Mochtar, I. Renreng, and H. Arsyad, "Sodium bicarbonate treatment on mechanical and morphological properties of coir fibres," *International Journal of Automotive and Mechanical Engineering*, vol. 15, no. 3, pp. 5562–5572, 2018.

[2] M. A. Rahuman, S. S. Kumar, R. Prithivirajan, and S. G. Shankar, "Dry sliding wear behavior of glass and jute fiber hybrid reinforced epoxy composites," *International Journal of Engineering Research and Development*, vol. 10, no. 11, pp. 46–50, 2014.

[3] S. Sanjeevi, V. Shanmugam, S. Kumar et al., "Effects of water absorption on the mechanical properties of hybrid natural fibre/phenol formaldehyde composites," *Scientific Reports*, vol. 11, pp. 1–11, 2021.

[4] A. Sreenivasulu, K. S. Ashraff Ali, P. Arumugam et al., "Investigation on thermal properties of tamarind shell particles reinforced hybrid polymer matrix composites," *Materials Today: Proceedings*, vol. 59, Part 2, pp. 1305–1311, 2022.

[5] 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.

[6] V. Fiore, T. Scalici, and A. Valenza, "Effect of sodium bicarbonate treatment on mechanical properties of flax-reinforced epoxy composite materials," *Journal of Composite Materials*, vol. 52, no. 8, pp. 1061–1072, 2018.

[7] N. E. Zafeiropoulos, C. A. Baillie, and J. M. Hodgkinson, "Engineering and characterisation of the interface in flax fibre/polypropylene composite materials. Part II. The effect of surface treatments on the interface," *Composites. Part A, Applied Science and Manufacturing*, vol. 33, no. 9, pp. 1185–1190, 2002.

[8] M. Evtimova, M. Vlahova, and A. Atanassov, "Flax improvement by biotechnology means," *Journal of Natural Fibers*, vol. 2, no. 2, pp. 17–34, 2005.

[9] S. Sekar, S. Suresh Kumar, S. Vigneshwaran, and G. Velmurugan, "Evaluation of mechanical and water absorption behavior of natural fiber-reinforced hybrid biocomposites," *Journal of Natural Fibers*, vol. 19, no. 5, pp. 1172–1782, 2022.

[10] T. Raja, V. Mohanavel, S. Suresh Kumar, S. Rajkumar, M. Ravichandran, and R. Subbiah, "Evaluation of mechanical properties on kenaf fiber reinforced granite nano filler particulates hybrid polymer composite," *Materials Today: Proceedings*, vol. 59, pp. 1345–1348, 2022.

[11] 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.

[12] V. Ganesan and B. Kaliyamoorthy, "Utilization of Taguchi technique to enhance the interlaminar shear strength of wood dust filled woven jute fiber reinforced polyester composites in cryogenic environment," *Journal of Natural Fibers*, vol. 19, no. 6, pp. 1990–2001, 2022.

[13] A. Atiqah, M. N. M. Ansari, M. S. S. Kamal, A. Jalar, N. N. Afeefah, and N. Ismail, "Effect of alumina trihydrate as additive on the mechanical properties of kenaf/polyester composite for plastic encapsulated electronic packaging application," *Journal of Materials Research and Technology*, vol. 9, no. 6, pp. 12899–12906, 2020.

[14] F. Sarker, P. Potluri, S. Afroj, V. Koncherry, K. S. Novoselov, and N. Karim, "Ultrahigh performance of nanoengineered graphene-based natural jute fiber composites," *ACS Applied Materials & Interfaces*, vol. 11, no. 23, pp. 21166–21176, 2019.

[15] F. Perreault, A. Fonseca De Faria, and M. Elimelech, "Environmental applications of graphene-based nanomaterials," *Chemical Society Reviews*, vol. 44, no. 16, pp. 5861–5896, 2015.

[16] S. A. Hallad, N. R. Banapurmath, V. Patil et al., "Graphene reinforced natural fiber nanocomposites for structural applications," *IOP Conference Series: Materials Science and Engineering*, vol. 376, no. 1, 2018.

[17] A. Karthikeyan, K. Balamurugan, and A. Kalpana, "The effect of sodium hydroxide treatment and fiber length on the tensile property of coir fiber-reinforced epoxy composites," *Science and Engineering of Composite Materials*, vol. 21, no. 3, pp. 315–321, 2014.

[18] V. Ganesan, V. Shanmugam, B. Kaliyamoorthy et al., "Optimisation of mechanical properties in saw-dust/woven-jute fibre/polyester structural composites under liquid nitrogen environment using response surface methodology," *Polymers*, vol. 13, no. 15, p. 2471, 2021.

[19] G. Velmurugan and K. Babu, "Optimization on mechanical behavior of hemp and coconut shell powder reinforced epoxy composites under cryogenic environment using Grey-Taguchi method," *SSRN Electronic Journal*, vol. 2019, 2019.

[20] G. Velmurugan, K. Babu, L. I. Flavia, C. S. Stephy, and M. Hariharan, "Utilization of Grey Taguchi method to optimize the mechanical properties of hemp and coconut shell powder hybrid composites under liquid nitrogen conditions," *IOP Conference Series: Materials Science and Engineering*, vol. 923, no. 1, 2020.

[21] V. S. Srinivasan, S. Rajendra 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.

[22] L. Fiore Vincenzo, "Effect of stacking sequence and sodium bicarbonate treatment on quasi-static and dynamic mechanical properties of flax/jute epoxy-based composites," *Materials*, vol. 12, no. 9, p. 1363, 2019.

[23] S. Kalyana Sundaram, S. Jayabal, N. S. Balaji, and G. Bharathiraja, "Study of chemical and mechanical properties of Dharbai fiber reinforced polyester composites," *Advanced Composite Materials*, vol. 27, pp. 107–117, 2018.