

Research Article

Nanotitanium Oxide Particles and Jute-Hemp Fiber Hybrid Composites: Evaluate the Mechanical, Water Absorptions, and Morphological Behaviors

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Organic fiber-based biocomposites have gained prominence in a variety of sectors over the last four to five years due to their exceptional mechanical and physical properties. Natural fiber-based composites are increasingly being employed in autos, ships, airplanes, and infrastructure projects. The current study will look at the effect of nanotitanium oxide (TiO₂) fillers on the properties of hybridised jute-hemp-based composites. In this work, TiO₂-filled biocomposites were created using the hand layup method in hybrid jute-hemp composites containing jute fiber mats, woven hemp mats, and epoxy resin. After nanotitanium oxide fillers were injected in various weight proportions, the mechanical properties of fiber-reinforced polymers were investigated. The mechanical properties of laminated composites were tested using the ASTM standard. Compared to 2 and 4 wt.% of TiO₂, the 6 wt.% was provided the highest mechanical strength. Among the different types of specimen, the E-type specimen (30 wt.% of hemp, 7 wt.% of jute, 57 wt.% of epoxy, and 6 wt.% of TiO₂) gives their highest contribution, i.e., for tensile 24.21%, for flexural 25.03%, and for impact 24.56%. The scanning electron microscope was utilized to analyse the microstructures of nanocomposites.

1. Introduction

The utilization of composite materials has increased at an astounding rate, and these materials today have a remarkable and wide variety of uses. Minimal weight, strong fatigue tolerance, high corrosion resilience, insulation, and low coefficient of thermal expansion are key benefits of composites over several metallic materials. Polymer matrix composites

(PMCs) offer outstanding physical and thermal qualities, like high specific toughness, as well as high toughness and rust resistance. The researchers emerged as viable alternatives to traditional metals in a wide range of applications, including aeroplanes, warships, housing, vehicles, microelectronics components, and maritime construction [1, 2]. The resources used throughout the airframe of a Boeing 777 contain 50% aluminium and 12% polymers by weightiness. However, in

the completely redesigned Boeing 787 aviation, the proportions by heaviness for aluminium and polymers have altered to 22% and 55%, correspondingly. Fiber-reinforced polymer compounds have a number of appealing qualities, like high stiffness, fracture toughness performance and damage tolerance levels, high thermal stability, nonmagnetic characteristics, oxidation resistance, and low manufacturing energy consumption [3, 4]. Fiber glass-reinforced glass, polypropylene, and graphene are the most prevalent artificial fibers. In polymer matrix composites, harder and tougher fibers can be added to increase the strength and rigidity of the polymers. Because of its outstanding characteristics, such as high specific fracture toughness, adjustable electrical conductivity, temperature resistance, high fatigue barrier properties, and appropriateness for the fabrication of numerous contour substances, fiber-reinforced composites have been widely used. In numerous applications, composite materials have replaced traditional architectural materials like metals, hardwoods, and iron [5, 6]. Car manufacturing, aeroplane production, wind energy plants, yachts, and warships are all examples of composites' uses. The way things are manufactured has altered thanks to filler reinforced structural polymeric or thermoplastic composites. Authors may now be seen not just in air and ground transportation vehicles, sports gear, and electronics but also in bullet barriers, weaponry, percussion equipment, fashion items, and much more. The requirement for materials of good physical qualities, in combination with lighter weight and low price, grows as demand grows [7]. This necessitates a continuous hunt for new ingredients, additions, and production procedures. The standard strategy is to look for a joint that attaches the reinforcement to the matrix and enhances the transfer of load but does not cause considerable matrix fouling at the boundary, permitting crack propagation during dynamic loads [8]. Because of their improved properties, nanostructured membranes made of polymer matrices and nanomaterials/nanofillers have piqued the interest of researchers and industry in their application, leading to high barrier packing for food and gadgets for automobiles and aviation. They offer excellent feature upgrades, including increased thermal and mechanical characteristics, permeability resilience, and flame retardancy at different filler levels, as compared to their typical microscopic and macroscopic or clean equivalents [9, 10]. In the last twenty years, polymer-based nanocomposites have attracted a lot of interest from academia and industry. Different polymer matrixes and nanoparticles have indeed been studied in different configurations. The addition of a small amount of nanofiller has proved to improve the physical characteristics of polymer matrices dramatically. The shape, size, content, and degree of aggregation of the filler, as well as the amount of matrix-filler adherence, have a major impact on the characteristics of a polymeric-filled composite. The use of nanomaterials as fillers creates a bigger dynamic and interactive zone, which might lead to significantly stronger couplings with matrices and a better end product. Nanoparticles can also provide nanocomposite distinctive features like electrical, photonic, magnetism, or transporting capabilities, which opens up endless possibilities for rapid technological use. Synergistic effects from the combining of

separate components contribute to improved properties in polymer-based composites [11, 12]. These gains may be approximated using mixing procedures in ordinary composites, but these begin to fail in nanocomposites since interface connections among constituents become highly important for determining bulk characteristics. Particle polymer composites are made up of microparticles or nanofillers of various types and sizes scattered arbitrarily in matrix materials. Due to tear dulling, fracture deflecting, and fracture anchoring hardening processes, the introduction of titanium oxide and aluminium oxide nanoparticles in epoxy reaches the maximum hardness. The incorporation of nano-SiO₂ increased mechanical characteristics and breakage durability with weight concentration owing to matrix deformations, region buffering, void development, particle-matrix delamination, and localised shearing band hardening mechanisms. Formulation, constituent characteristics, architecture, and interface contact all influence the biomechanical, physical, and chemical characteristics of nanostructured materials, particularly yield strength. If nanoparticles possess an anisometric topology, the direction of the nanoparticles should be considered in estimating material properties. The efficacy of stress transmission among filler and matrix affects the intensity of a particle-filled composite. The TiO₂ nanoparticles are now one of the more intriguing substances [13, 14]. They are gaining popularity not only because of their unusual features but also because of their prospective uses in sectors like paints, perfumes, catalysis, and catalyst support. After ultrasonically processing, the mechanical and absorption properties of polymeric composites containing TiO₂ nanoparticles and epoxy were associated to composite samples containing TiO₂ microscopic particles and epoxy, as well as plain resin. The nanocomposites with proper dispersions of nanoparticles at a loading of 10 wt.% showed a unique mix of attributes, including improvements in impact resistance and elasticity, but also improvements in cyclic loading and swelling tolerance, all while preserving hardness. In comparison to the clean resin, the nanobased composites demonstrated no gain in abrasion confrontation and a reduction in failure to strain [15, 16]. The goal of this study is to see how nanotitanium oxide fillers affect the characteristics of hybrid jute-hemp composites. Hand layup techniques were used to create the composites. The ASTM standard was used to test and analyse mechanical qualities such as tensile, bending, and impact. A scanning electron microscope was used to perform the microstructural study.

2. Experimental

2.1. Materials. To change the epoxy matrices, TiO₂ particles with a size of 30 nm were utilized as caulking substantial. As a reinforcing material, a 350 gsm commercially available jute fiber chop strand mat was employed. As a reinforcing material, a 250 gsm woven hemp mat with an average thickness of 0.65 mm was employed. GVR Fiber Industry, Madurai, Tamil Nadu, India, provided both natural fiber mats. Naga Chemical Ltd. in Chennai, Tamil Nadu, India, provided the TiO₂ filler. Figure 1 reveals the reinforcement materials and TiO₂ fillers.

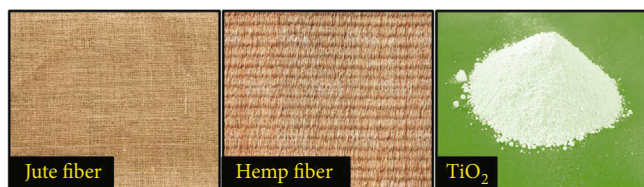


FIGURE 1: Reinforcement and TiO_2 filler materials.

2.2. Alkaline Processing. Alkaline treatment is among the most often utilized chemical methods when natural fibers are combined with polymer to produce a composite. The most notable change generated by alkaline treatment is the breakage of hydrogen bonds in the underlying network, resulting in enhanced surface quality. During alkalization, fibers are immersed in a NaOH solution for a specific period of time. The hemp mat was treated chemically with sodium hydroxide in the current study. For four hours, ordinary hemp and jute were immersed in a container; it contains a 5% NaOH solution. After that, the fiber mats were air dried at ambient temperature [17].

2.3. Fabrication of Hybrid Composites. Depending on the mass of the tiny titanium oxide nanoparticles to an overall weight of the jute, hemp, epoxy resin, and nanotitanium oxide particles, the mass proportions of the nano- TiO_2 filler in the composites were 2 percent, 4 percent, and 6 percent. To make the nano- TiO_2 -mixed epoxy resin, mechanical stirring was used to mix the nano- TiO_2 into the epoxy resin, followed by the addition of the suitable hardener. Hand layup was used to create the hybrid composites, which consisted of three layers of hemp, jute, and hemp. Hemp was used for the bottom and top layers, while jute was used for the middle layer. To make the created hybrid fiber-reinforced plastics easier to remove, a releasing agent was first placed across a flat moulding. A thick coating of nano-scale TiO_2 blended epoxy resin was placed over the release chemical layer. The bottom layer of hemp was then applied to the mould's surfaces. The nanoscale TiO_2 -mixed epoxy resin was then sprayed onto the surface of the hemp that had previously been put in the mould and distributed evenly with a brush. To eliminate any air trapped, a roller was dragged through the bottom layer with little force. A thin coating of nano- TiO_2 epoxy resin was applied once again. The experiment was replicated with the addition of next interfacial layer of jute. Table 1 shows the list of parameters and their constraints of nanocomposites.

2.4. Mechanical Testing. The fabricated composite specimens were cut rendering to ASTM standard of D 638-03 replicas with a dimension of $150 \times 15 \times 3$ mm for tensile testing, ASTM D-790 (width 10 mm, length 125 mm, and thickness 3 mm) for flexural testing, and ASTM D-256 (width 12.7 mm, length 64 mm, and thickness 3 mm) for impact testing as shown in Figure 2.

2.5. Fractographic Study. SEM was employed to conduct fractographic investigations of fractured composite samples. The specimens were laved, dehydrated, and surface coated

TABLE 1: List of parameter and their levels of nanocomposites.

Specimen type	Woven hemp fiber (wt.%)	Woven jute fiber (wt.%)	Epoxy matrix (wt.%)	Titanium oxide (wt.%)
A	0	0	100	0
B	30	7	63	0
C	30	7	61	2
D	30	7	59	4
E	30	7	57	6

with 10 nm of gold earlier SEM clarity to enhance the composites' electric conduction.

3. Result and Discussion

The following session briefly discusses the mechanical goods like flexural, tensile, and impact characteristics of polyester composites based on their input parameters.

3.1. Outcomes of Hybrid Nanocomposites. The mechanical properties like tensile, flexural, and impact behavior of hemp-jute-based titanium oxide filler composites are shown in the figure. This research found that the weight percentage of nanoparticles is directly proportional to the test results. Because the mechanical characterization of hybrid composites increased when the weight percentage of titanium oxide particles was increased in the matrix mixture, the characterization strength of nanocomposites depends on the type of filler materials, adhesion between the matrix mixture and the fibers, and the extent of load shearing capacity. The interfacial stiffness, quality of adherence components, and their static adherence strength played the major roles in determining the composite strength. It helps to transfer the stress and elastic deformation from the matrix to the fiber or fillers and the fiber to the matrix. Figure 3 demonstrates the mechanical properties of hybrid nanocomposites [18, 19].

When compared to microscopic composites, nanomaterials have a higher percentage of interaction. The particles are unable to carry any part of the externally applied if the filler matrix contact is deprived. In this situation, the composite's strength cannot exceed that of the plain matrix material. The elastic modulus of nanoparticle composites could be greater than that of the matrix material if the interaction seen among the filler and the matrices is good enough. Because of the increased high strength nano- TiO_2 filler particles and decreased epoxy in the matrix, the mechanical characteristics of the hybrid composite improve with the inclusion of nanocomposite filler particles [20, 21]. The hybrid composite's enhanced mechanical, flexural, and impact strength indicates that stresses are effectively transmitted over the interaction. The mechanical and physical properties of hybrid jute-hemp hybrid composites are enhanced owing to the cooperative accomplishment of nano- TiO_2 fillers, hemp, jute, and epoxy. Figure 4 shows different specimen contributions in % (a) tensile, (b) bending, and (c) impact strength of hybrid nanocomposites.



FIGURE 2: Setup of impact testing.

With the inclusion of nano-TiO₂ filler particles, the mechanical characteristics of the hybrid composite are greatly enhanced. The tensile strength of the hybrid composites based on 0 wt.% TiO₂ was 58 MPa for the hybrid composites with 0% TiO₂ to 74 MPa for the hybrid composites with 6% TiO₂. Flexural strength improved from 98 MPa at 0% TiO₂ to 143 MPa at 6% TiO₂. The impact strength increased from 49 kg/m² with 0% TiO₂ to 67 kg/m² with 6% TiO₂. The inclusion of nano-TiO₂ filler increases the tensile strength, flexural strength, and impact strength of hybrid composites. Because of fracture-tip dampening, blow refraction, and blow restraining strengthening processes, the inclusion of TiO₂ nanoparticles to fiber-based composites boosted strength. Figures 4(a)–4(c) demonstrate the various sample contribution on mechanical properties. From Figure 4, in tensile, most contributed % is attained in E specimen; in bending and flexural test, most contributed sample is E, respectively.

3.2. Morphological Analysis. Scanning electron microscopy was used to examine the characteristics of tensile surface defects and the fiber-matrix interface. Others have used this approach to determine the stiffness modulus and durability of nanocomposites. Figures 5(a)–5(c) show the SEM micrographs of natural fiber-based nanocomposites after tensile fracture. The TiO₂ dispersion in the epoxy matrix is remarkably constant (Figure 5(a)). At greater loadings, however, the fillers tend to form agglomerates. It is generally recognised that adequate filler dispersion in the matrix is a key aspect in achieving good mechanical characteristics [17, 22, 23]. The use of a greater magnification allows for the observation of a single TiO₂ particle with longitudinal shapes. The aggregation of TiO₂ particles can be seen in Figure 5(b), with the biggest ones being seen using the SEM. It is well known that as filler loading increases, so does the ability to agglomeration.

Polymer discomfort, fiber breaking, and polymer and reinforcement adhesive catastrophe have all been recognised as failure modes for typical fiber-based polymerics in the literature. A weedy border or inadequate contact between fiber and matrix might cause fiber pullout rather than fracture, lowering mechanical properties. In this study, several combinations of these failures were discovered, depending on the nanocomposite's composition. Figure 5(b) depicts a typical SEM micrograph of nanocomposite sample 6 wt.% TiO₂. Fiber pullout and its breakage are shown in the SEM images [24]. As the organic resin content increased, the interaction holes surrounding pull-out fibers grew larger, signifying worse adhesion between the fiber and the biobased matrix. As a consequence, the interface aspects of pull-out failures were examined. The interfacial separation of nanocomposites containing 6 wt.% TiO₂ was the same as that of nanocomposite. This shows that TiO₂ reinforcing has no effect on the fiber-matrix interfacial bonding. Tensile studies support the concept that a weaker interface generates a more spectacular pull-out spectacle, since a drop in mechanical properties was observed as the quantity of organic-based resin material rose as shown in Figure 5(c). The pullout of fiber enables for more oomph to be diffused at the boundaries, which is consistent with the improved impact characteristics and endurance during the chemical type epoxy treatment [16].

4. Water Absorption Behavior

Figure 6 depicts the amounts of moisture content in several composite materials. The rate of water updating for all composite materials was significant at first, but it has since become practically constant and has decreased in the final phase. According to the findings, with longer time durations, all composite materials display a significant moisture absorption rate. Moisture content varied from 12 to 22% after the first day, and it rose to 12–38% for various composites created. Of all the composite materials, the hybrid nanocomposites made with titanium oxide showed the maximum amount of water attraction. This might be owing to the improved hydrophilic behavior of the nanocomposite following fiber mixing and TiO₂ incorporation. The hemp/jute with 6 wt.% TiO₂ (model E) combination had the maximum moisture uptake values when associated to the other amalgams.

This is owing to the large amount of (OH) assemblages current on hemp fiber surfaces. The amount of hydroxyl group and microvoids in the hemp/epoxy composites increased, leading in a considerable rise in moisture fascination. The hybrid wood-hemp combination, on the other hand, absorbed the least amount of water. The hybrid nanocomposite with hydrophilic titanium oxide, on the other hand, absorbed more moisture than the hybrid composite. As compared to 0, 2, and 4, the 6 wt.% of TiO₂-filled hybrid composites exhibits lower moisture absorption. This is owing to the proper spreading of nanoparticles in the resin medium mixture. It helps to reduce the formation of voids, and the fiber pulls out. This may help to increase the moisture absorption characteristics [25].

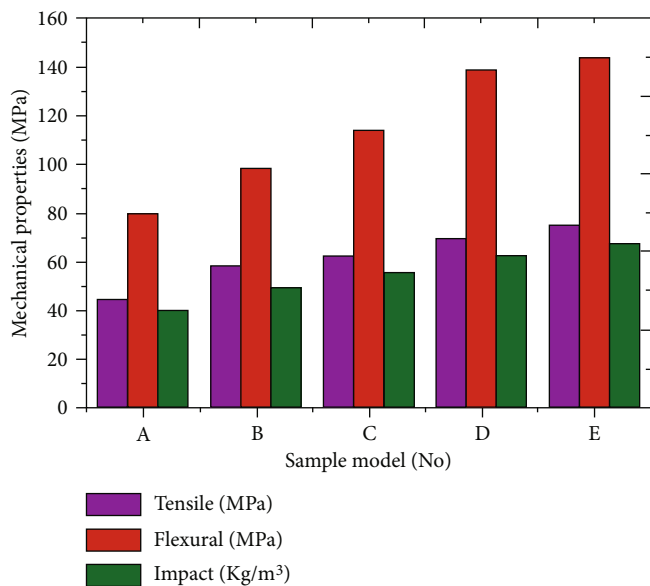


FIGURE 3: Mechanical properties of hemp/jute/nano-TiO₂-based hybrid nanocomposites.

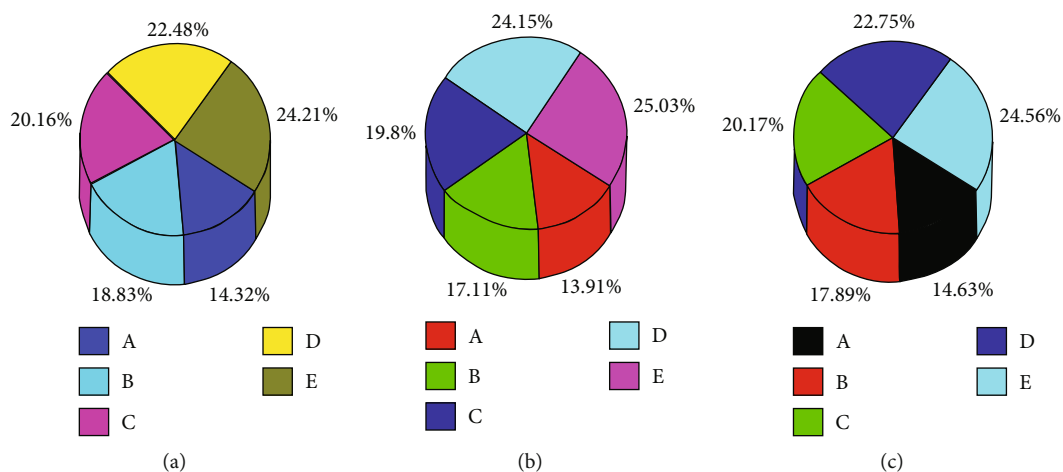


FIGURE 4: Different specimen contribution in % (a) tensile, (b) bending, and (c) impact strength of hybrid nanocomposites.

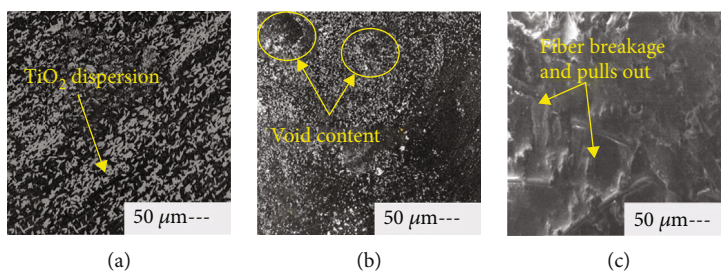


FIGURE 5: Microstructural analysis of TiO₂-filled hemp- and jute-based hybrid composites.

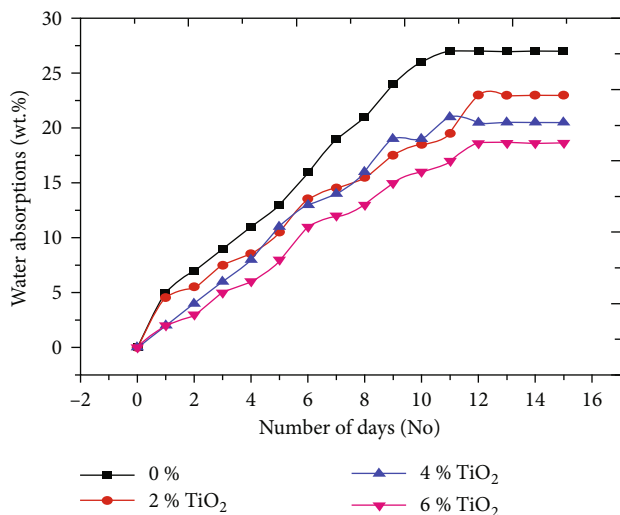


FIGURE 6: Water absorption behavior of TiO₂-filled hybrid nanocomposites.

5. Conclusion

As per the experimental outcomes, the use of nano-TiO₂ filler particles improved the mechanical properties of hybrid composites.

- (i) The 6 wt.% TiO₂ provided the maximum mechanical strength when compared to the 2 and 4 wt.% TiO₂
- (ii) The E-type specimen provides the most to the different types of specimens, with a contribution of 24.21 percent for tensile, 25.03 percent for flexural, and 24.56 percent for impact
- (iii) The creation of TiO₂ particle-hybrid jute-hemp composites indicated that these nanocomposites with excellent mechanical characteristics may be employed in a variety of applications. When compared to the A, B, C, and D types, the E-type specimen has the highest mechanical strength with 6 wt.% TiO₂. The dispersion of nanoparticles in the epoxy mixture was homogeneous in this specimen. SEM pictures corroborated this

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is 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.

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