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Research Article

Effect of Fiber Mixing and Nanoclay on the Mechanical Properties of Biodegradable Natural Fiber-Based Nanocomposites

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Combining two types of fibers may aid in improving the fundamental properties of organic fiber-reinforced hybrid polymeric materials. Biomaterials created from raw materials are gaining appeal in the industrial sector due to their high quality, as well as sustainability and environmental considerations. Natural fiber-reinforced hybrid nanocomposites were created in this work using a compression moulding technique with wood particles, hemp fiber, polypropylene, and montmorillonite nanoclay. Following that, the impacts of fiber mixture and vermiculite on mechanical and compostable qualities were studied. Both the coir and the hemp fibers were alkali-treated to minimize their hydrophilic nature before even being employed. Using universal tensile testing equipment, the mechanical characteristics of the prepared composites were investigated and found to be improved following fiber blending and nanoparticle inclusion. The maximum strength was occurred at the combinations like 10 wt. % of wood particle, hemp, nanoclay, and 70% of polypropylene matrix. Scanning electron microscopy showed that nanoclay significantly increased the adherence and interoperability between fiber and the polymer matrices. The good biocompatibility and water absorption capabilities of the nanocomposite were increased by mixing fibers, but nanoparticle additions seemed to have the opposite impact.

1. Introduction

Agricultural leftovers that are plentiful and present difficulties when processed have recently been the topic of investigation due to growing awareness of environmental concerns. Field crop leftovers are frequently generated in billions of tonnes and are cheap; though solitary, a minor percentage of the waste is used as domestic petroleum or nourishment, while the majority is charred in the turf, polluting both the air and the environment. The challenge might be solved by using these leftovers as reinforcement material in polymer composites. It will also increase the value of the agrifood stream restraint. Fabric-based polymer matrix composites have lately been enough to substitute high strength concrete in the building and construction industry. Natural fibers are replacing traditional synthetic materials as reinforcing agents because of their nonpollutant, anticorrosiveness, good mechanical properties, light

Table 1: Natural fibers and their mechanical properties.

Fibers	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Abaca	1.5	980	—	—
Banana	1.35	355	33.8	5.3
Coir	1.25	220	6	15-25
Cotton	1.51	400	12	3-10
Flax	1.4	800-1500	60-80	1.2-1.6
Hemp	1.48	550-900	70	1.6
Jute	1.46	400-800	10-30	1.8
Kenaf (bast)	1.2	295	—	2.7-6.9
Pineapple	1.5	170	82	1-3
Ramie	1.5	500	44	2
Sisal	1.33	600-700	38	2-3

Figure 1: Abstraction of cannabis fiber from cannabis shrub.

weight, low price, recyclability, and good biocompatibility, as well as their good ecological effects [1, 2]. The use of renewable resources in polymeric composites may aid in reducing CO_2 emissions from plastic burning. Despite its usefulness, organic fiber-based composite materials have lesser elasticity, tensile strength, durability, and water resistance than artificial fiber-based composite materials. To address these challenges, natural materials might be combined with a tougher inorganic or organic fiber in polymer matrices. This will result in hybrid composites that make better use of the best attributes of the components, resulting in an optimal, superior, and more cost-effective combination [3]. Manufacturers may customize composites using organic fiber-reinforced hybrid polymeric materials at a cheap cost, which is not possible with binary mixtures of one fiber and one filler spread in the matrices [4]. Organic cellulosic fibers are reusable, nonabrasive, have good mechanical qualities, and are ecologically benign, making them desirable in engineering disciplines including automobiles and construction. Wood, jute, ramie, and hemp, out of all natural materials, have the greatest opportunity as hybrid composite reinforcement across the globe [5]. Due to its light weight, specific strength, biodegradability, simple accessibility, recyclability, and low price, wood fiber has achieved tremendous popularity as a filler in polymeric materials. Wood-reinforced polymers of various kinds have previously been developed and marketed [6]. The inclusion of wood fiber increased the elasticity, rigidity, toughness, durability, and flame retardancy of the polymers [7]. Hemp, on the other hand, is the toughest natural fiber since it is derived from the stem of the hemp plant. Cannabis is a millennia plant that is today regarded as one of the most environmentally friendly commercial materials. Herbs were sometimes mistakes to their resemblance to marijuana indica. Hemp could be grown in a wide range of climatic areas on a variety of extremely good, upgrading circumstances with such a wonderful yield even without agrochemicals, attaining elevations of 2-3 meters and a radius of 6-internal diameter. The cannabis seeds are regarded as a poor socioeconomic organic metabolic end due to its high hygroscopicity and tannin content. Processing techniques could result in better cannabis strands with an undigested surface of the fiber and more customization. Cannabis threads implanted in a lignocellulosic or phenolic foundation are produced into various architectural configurations [8, 9]. Cannabis fiber building has previously been extensively researched, resulting in useful, in-depth information being available in cultural canon. Hemp fibers are longer, stronger, and harder than other plant fabrics like silk, and they are also coarser; so, they are used in engineering fields. As a result, composites (airline sector, sporty products, etc.), structural and building materials, geotextiles,

Table 2: Parameters and their constraints of nanocomposites.

Sample No.	Wood particle (wt. %)	Hemp (wt. %)	Nanoclay (wt. %)	Polypropylene matrix (wt. %)
1	30	0	0	70
2	0	30	0	70
3	15	15	0	70
4	15	0	15	70
5	0	15	15	70
6	10	10	10	70

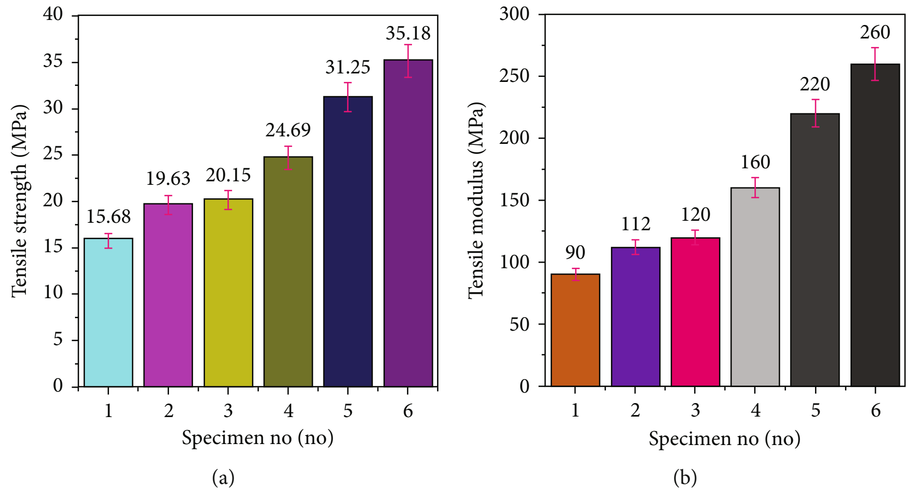

Figure 2: (a) Tensile strength. (b) Tensile modulus of nanohybrid composite.

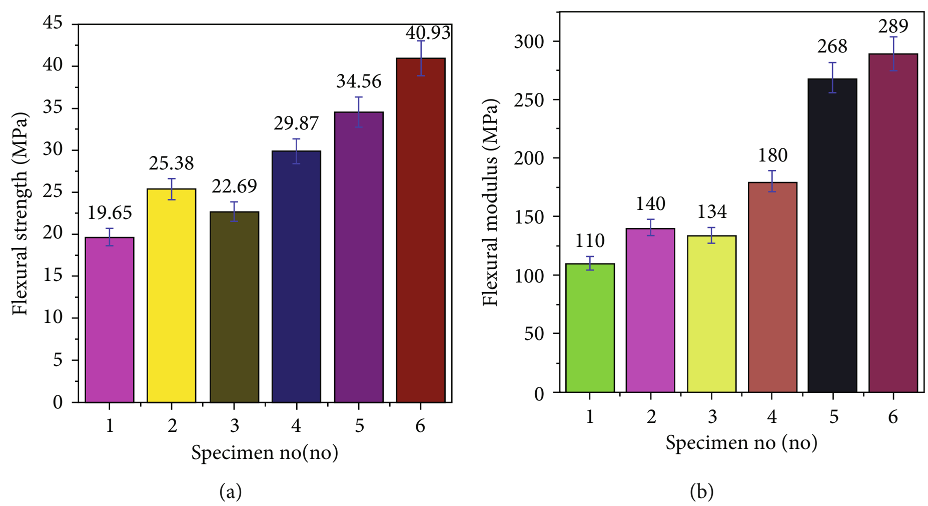

Figure 3: (a) Flexural strength. (b) Flexural modulus of nanohybrid composite.

and other uses account for nearly a quarter of the marijuana fibers utilized in commercial processes. Throughout their life span, hemp fibers exhibit a variety of forms, thicknesses, topologies, and characteristics. In comparison to other cellulosic fibers, this has a considerable lignin content, moderate cellulose content, and a large microfibril inclination, which results in poorer tension strength and increased elasticity. This chemical structure minimizes the product's reactivity with polymeric radical generated throughout manufacturing, as well as its serviceability [10, 11], and the mechanical possessions of different threads is revealed in Table 1.

Nanocomposites outperform conventional polymers in terms of weight, durability, and simplicity of processing [12]. Nanomaterials are made up of tiny components with the lowest single measurement in the nanometric variety (i.e., less than 100 nm) that permits them to fill a matrix more efficiently. The nanoparticles known as "nano clays" are made up of stacked crystalline silicon dioxide. The nanoclay seems to have a higher surface area and a porous structure, resulting in significant interface contact between the polymers and the nanofiller, enhancing the polymer characteristics dramatically. Because of their exceptional mechanical, visual, electronic, and fire reserve capabilities, nanocomposites supplemented using biological and chemical nanostructures have attracted a lot of interest [13, 14]. Nanocomposites are a new type of nanocrystalline hybridization material made up of biodegradable polymers with one or more inorganic nanoparticles. They constitute the nexus of nanotechnology, materials engineering, and biology [15]. The creation of nanocomposites with improved thermodynamic, physical, and multifunctional qualities has been pursued. Furthermore, biopolymer-based materials made using renewable technologies have demonstrated digestibility and biocompatibility in pharmaceuticals, packaged food, and agricultural applications. Numerous research have been directed on normal fabric-strengthened polymeric materials that have been hybridized with synthetic fiber [16, 17]. On the other hand, natural fiber hybrid nanocomposite and their combination with natural fibers and nanoclay, on the other hand, have received much interest. The primary purpose of this work was to determine how combining fiber types and adding nanoclay to wood/hem/nanoclay hybrid

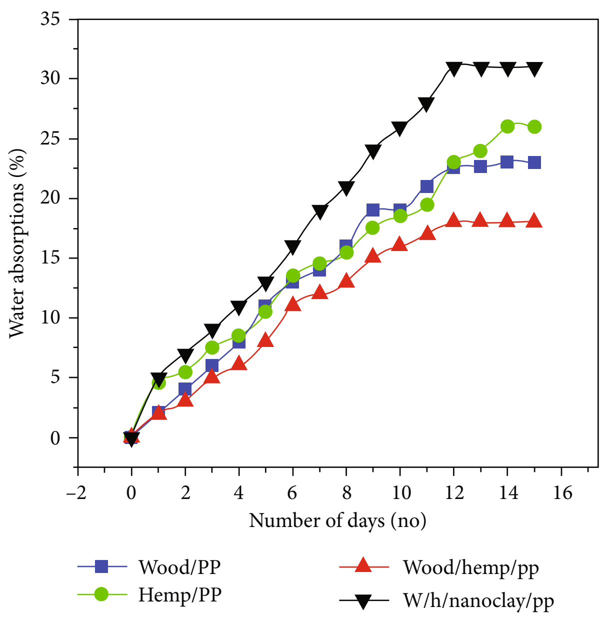

Figure 4: Water absorption behavior of wood/hemp/nanoclay/PP-based hybrid composites.

polypropylene biomaterials influenced their mechanical and biodegradable properties.

2. Resources and Techniques

2.1. Resources. In the composite system, wood fiber, hemp fiber, and nanoclay were employed as reinforcing fillers. Rithu Timber Industry in Madurai, Tamil Nadu, India, processed and gathered wood fiber. A GVR fiber factory in Madurai, Tamilnadu, India, processed and gathered hemp fiber. The nanoclay, sodium hydroxide, and polypropylene (PP) were provided by the Naga chemical company in Chennai, Tamilnadu, India. Figure 1 shows demonstrations of the subtraction procedure of hemp fiber from the hemp plant.

2.2. Alkaline Treatment. Unprocessed cannabis was washed in 2-3% scrubbing chemicals for 30 minutes at 50-60°C and disinfected with plain water before curing in an elevated furnace at around 80°C for 30 minutes, as stated. Washed threads became referred to as "raw threads." The threads are then disinfected via immersing them in a 2 : 1 combination of toluene and methanol for 60 to 78 h at 35°C, followed by a vigorous rinsing in 24 hours. Finally, the fibers were again engrossed in a 5 percent NaOH solvents at ambient conditions for 4 hours.

2.3. Fabrication of Hybrid Composites. Firstly, a stainless-steel mould with a size of 300 × 300 × 3 mm was refined. The matrix material was mixed well with the hardener to create a good matrix system. The compression moulding technique was used to construct the composite from wood/hemp/nanoclay combinations. By hand stirring with a glass rod, varying weight percents of nanoclay powder were disseminated in the produced polypropylene. This matrix mixture was scattered over the mould's layers of fibers. The combinations were warmed to 170°C inside the compression moulding machine for 15 minutes. The composite was chilled in the atmospheric air for numerous proceedings to avoid any contraction that may have occurred throughout the abstraction method. The parameters of the nanocomposites are listed in Table 2. That parameter provides better improvement with mechanical properties which was proved by the various researchers [15–17].

2.4. Testing of Hybrid Composites. For tension behavior, the produced laminate specimens were taken and converted to ASTM D 638-03 analogues and ASTM D-790 for bending behavior [7]. Morphological examinations of cracked laminate material were carried out using SEM. Prior to SEM analysis, the samples were being laved, desiccated, and then chemically covered using tens of nanometers of golden to improve the ionic properties of the mixtures. The models were dehydrated for 1 hour at 70°C in a microwave and then cooled to a consistent weight in the outdoors. Following that, the composite samples were submerged in purified water for 10 days, as per ASTM D570 [18]. Each and every day, the models were detached from the aquatic, cleaned with tissue paper, reweighed and quantified, and then returned to the liquid. The below formula was used to compute the water uptake rates in Equation (1).

$$\text{Moisture absorption} = \left(\frac{W_2 - W_1}{W_1}\right) * 100. \tag{1}$$

W_2 is the heaviness of the model after immersing, and W_1 is the heaviness of the model before absorption. Each kind of sample was subjected to five experiments, with the average results provided.

3. Result and Discussion

3.1. Tensile Strength. The tension properties and tensile modulus of different nanocomposites are shown in Figures 2(a) and 2(b). As shown in the figure, the tensile strength and tensile modulus of the hemp and polypropylene composite and the wood and polypropylene composite were almost identical. This might be related to the fact that wood and hemp fibers have comparable cellulose content [18]. Owing to its increased hemi cellulose concentration, hemp fiber is much more hydrophilic than wood fiber, while polypropylene is hydrophobic by nature. As a consequence, the hydrophilic hemp/wood and the hydrophobic polypropylene did not adhere properly, leading to a reduction in tensile strength and tensile modulus. When hemp fiber was mixed with wood fiber in PP and nanoclay was added, hybrid composites outperformed wood/PP and hemp/PP composites in terms of tensile strength and modulus. It is thought that composite materials with hemp or wood have higher tensile characteristics than other compositions because of fiber/matrix bonding, resulting in an even and efficient stress distribution across fibers. In addition, once nanoclay was added, the hybrid composites had the highest tensile strength and modulus. The nanoclay improved the mechanical characteristics of the composites by increasing

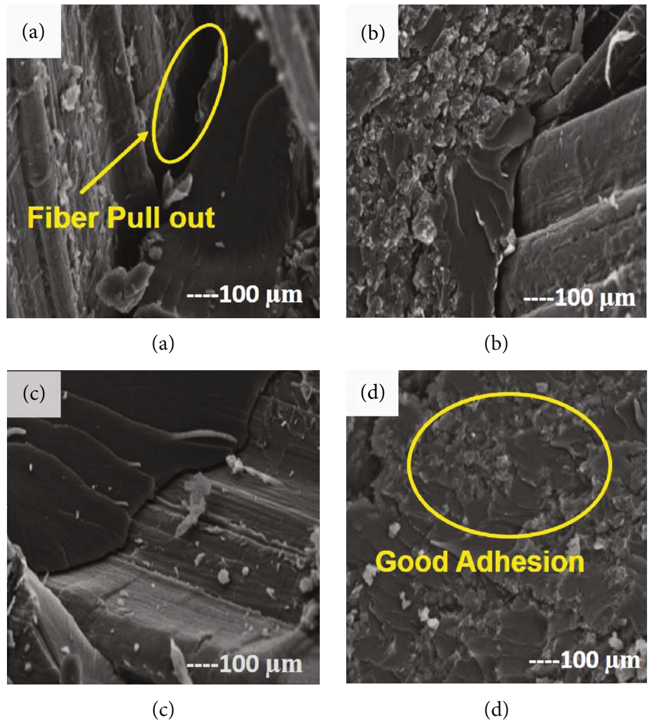

Figure 5: SEM image of (a) wood/PP, (b) hemp/PP, (c) wood/hemp/PP, and (d) wood/hemp/nanoclay/PP-based hybrid composite.

interfacial contact and adherence between both the fiber and the polymer matrices. A prior study had shown similar findings [19].

3.2. Flexural Strength. Flexural loading seems to be the most popular application rate of the deformation technique, which involves stretching a square sample to fracture or using a multiple point flexural evaluation technique. The maximal strain inside the substance at its yielding point is reflected in the flexural strength, and it is shown in Figures 3(a) and 3(b). It shows wood/PP composites, and the hemp/PP composites revealed the highest flexural strength. This result demonstrates that the adherence of hemp fiber was good compared to wood. Polypropylene composites' three-point bending strength increased with the addition of nanoclay. The addition of nanoclay increased the strength properties of the composite material, with a combination of wood/hemp/nanoclay/PP having the maximum bending strength value. The trends observed in the bending strength of the composite show the high surface area exhibited by the small filler particles, which improves the dispersion between the filler and the matrix and improves the interfacial bond [20, 21]. The SEM image discernibly shows the above trends. Polypropylene has brilliant adhesion to a variety of materials and can be further supported by adding fibers and particles. The outcomes show that hybrid nanoclay and wood/hemp/PP composites provide the finest consequences in both tensile and bending cases compared to other combinations.

3.3. Moisture Absorption Behavior. Figure 4 shows demonstrations of the moisture content levels of dissimilar composite materials. At the beginning, the rate of water updating for all composite materials was high, but this level has become almost consistent and reduced in the end phase. According to the findings, all the composite materials exhibit a high moisture uptake rate with the increased time durations. After the first day, moisture content ranged from 7 to 14%, and it climbed to 17 to 33% for various produced composites. The hybrid nanocomposites produced with nanoclay had the greatest percentage of water fascination of all the composite materials. This could be owing to the hybrid nanocomposite's enhanced hydrophilic character after fiber blending and nanoclay inclusion. In comparison to the other composites, the hemp/PP amalgamated had the maximum aquatic preoccupation standards. This is owing to the enormous number of OH groups found on the interfaces of hemp fibers. In the hemp/PP composites, the quantity of hydroxyl groups and microvoids increased, resulting in a significant increase in moisture fascination. The hybrid combination of wood and hemp, on the other hand, absorbed the least quantity of water. However, the accumulation of hydrophilic fillers to the hybrid nanocomposite occasioned in greater moisture absorption than the hybrid composite [15].

3.4. Fractography Analysis. The morphologies of nanomaterials were examined using SEM. Figure 5 presents the tension fracture boundaries of nanomaterials and hybridized nanofiber. The timber mixture as well as the hemp/PP mixture seemed to have the smoothest interfaces of all manufactured configurations, as illustrated in Figures 5(a) and 5(b), resulting in reduced material characteristics. The aspect of timber nanocomposites was equivalent to that of the timber and hemp/PP hybrids, as can be seen in Figure 5(c). Because the energy spent was low, the intermediate connection between the fibers and resin was not really able to withstand fiber pull-out after collision [22]. The hybrid composite had a more flawless texture than the individual materials, as shown in Figure 5(d). The introduction of nanoclay to the hybrid mixture enhances the material characteristics of the bio-based nanomaterials by increasing interfacial interaction and superficial roughness.

4. Conclusion

The mechanical and water absorption evaluation of many wood, hemp, nanoclay, and polypropylene-based nanocomposites was identified, and the following conclusions were obtained. Wood/hemp/nanoclay/PP hybrid composites outperformed wood/PP, hemp/PP, and wood/hemp/PP composites in terms of tensile and flexural strength. This might clearly demonstrate how effectively the polymer matrix and fibers interact. The nanoclay filler advances hybrid composite mechanical strength by boosting adhesive bonding strength. This is immediately apparent in SEM analysis. The wood/hemp/PP combination absorbs the most water when compared to other combinations. Nanoclay addition, on the other hand, has the opposite effect on these characteristics.

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

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