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Characterization of Polymer Based Natural Fibre Clay Nano Composites

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Abstract

Research on biocomposites is gaining significant attention due to the growing emphasis on sustainable and environmentally friendly materials. Biocomposites offer a promising alternative to traditional synthetic materials, such as plastics, which have environmental concerns like non-biodegradability and pollution. Natural fibers are often more affordable than synthetic materials, potentially leading to cost-effective products. Natural coir and jute biocomposites can be used in various industries, including automotive, construction, packaging, and textiles. Coir and jute fibre reinforced biocomposites can be prepared by adding nano clay in polyester resin. Though the glass and synthetic fibre reinforced composites possess higher specific strength, their applications are limited due to inherent higher production cost. Developing countries can use their own naturally available resources to produce low density composite materials at lower cost and reduce energy consumption. In this work, polymer-based clay nano composites were produced using natural coir and jute fibres. The mechanical strength of the composite materials was evaluated by physical testing. The various processing techniques as well as the influence of fibre type and moisture content on the mechanical properties of the material were discussed. The experimental results show significant improvement in the mechanical strength and therefore the potential applications and benefits of this innovation make it a promising candidate for replacing synthetic composites in numerous industries.

Keywords: Natural fibre reinforced, polymer based, biocomposite, Nano clay composite, mechanical properties

INTRODUCTION

A composite material typically comprises durable fibers embedded within a robust resin matrix. Examples of natural composite materials include wood and bone. Wood contains cellulose fibers embedded in a lignin matrix, whereas bone consists of hydroxyapatite particles within a collagen matrix. Composite materials offer the significant advantage of being more easily formed into complex shapes compared to their metallic counterparts. Using composite materials can reduce the number of parts needed for a given component and decrease the need for fasteners and joints, which might otherwise weaken the component. The disposal of non-biodegradable plastics has led to numerous environmental issues. The widespread use of these plastics has increased their presence in municipal solid waste, exacerbating pollution problems. Over the past decade, there has been substantial growth in the use of bio-composites in the automotive and decking markets. The automotive industry is increasingly driven by sustainability, green chemistry, and industrial ecology to seek alternative, eco-friendly materials for various applications. To address sustainability issues associated with synthetic materials in composites,

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materials from renewable sources are being sought to replace both the reinforcement element and the matrix phase. Utilizing natural fibers with polymers derived from renewable resources helps resolve many environmental concerns. Bio composites made from natural filler-filled biodegradable polymers are gaining attention for their ability to degrade naturally in soil. Natural fibers like flax, jute, hemp, and sisal have garnered significant attention as eco-friendly alternatives to glass and synthetic fibers in composite materials. The production of these natural fibers requires less energy and is more cost-effective compared to glass fibers.

Rosana et al. [1] demonstrated that adding cotton fibers to a starch-based commercial composite material maintains thermal stability and ensures biodegradation. They developed novel biocomposites using a biodegradable matrix reinforced with natural fibers to enhance properties and reduce costs. The study evaluated the impact of reinforcing a thermoplastic starch-based matrix (Mater-Bi KE03B1R) with cotton fibers on the composite's biodegradability. The biocomposites were subjected to a standardized accelerated degradation in soil test (DIN 53739) for 535 days to simulate post-disposal environmental conditions. Cotton fibers were incorporated into the pure thermoplastic starch-based matrix to ensure the degradation of the synthetic component. The surface degradation of cotton promoted microbial attack, resulting in more significant damage to the crystalline structure and superficial morphology of the reinforced biocomposites compared to pure Mater-Bi KE. Lawrence et al. [2] reported that biocomposite materials can serve as an alternative to petroleum-based composites in automotive applications. Leveraging the benefits of renewable resources, Garkhail et al. [3] developed two types of biodegradable composite materials using flax fibers as reinforcement and poly R-3-hydroxyalkanoates as a biodegradable polymer matrix. The first type involved producing natural-fiber-mat-reinforced thermoplastics through a compression molding method using needle-punched nonwoven flax fiber mats. The second type consisted of injection molding compounds based on short flax fibers. The study examined how the processing method and fiber content influenced the tensile and impact properties of these composites. The results suggested that adding flax fiber to poly 3-hydroxybutyrate could improve the material's cost to performance ratio. The exceptional strength and stiffness-to-density ratios and superior physical properties have made these biocomposites attractive for aviation and aerospace applications. Adam Quiter [4] provided a summary on the application of composites in aerospace. Using composite materials in commercial transport aircraft decreases the weight of the airframe, which leads to improved fuel efficiency and reduced operating costs. Kim et al. [5] examined the thermal properties of eco-composites made from polybutylene succinate (PBS) and agro-flour. Their study focused on how the mesh size and content of agro-flour influenced the thermal characteristics of the biocomposites. They found that increasing the agro-flour content enhanced the thermal stability, degradation temperature, and the peak temperature in the derivative thermo-gravimetric curve (DTGmax) of the biocomposites. However, the mesh size of the agro-flour did not affect the thermal degradation behavior of the composites. Averous and Le Digabe[6] analyzed biocomposites using lignocellulosic fillers (LCF) reinforced with a biodegradable aromatic co-polyester, polybutyleneadipate-co-terephthalate (PBAT). Their study demonstrated that combining biodegradable polymers with lignocellulosic fillers effectively addresses key challenges associated with biodegradable materials. Additionally, the incorporation of low-cost bio-fillers not only reduced the overall cost of the final product but also improved its properties.

Marc et al [7]. outline the fundamental design principles of biological structural composites and provide five examples: sea spicules, the abalone shell, the conch shell, toucan and hornbill beaks, and the sheep crab exoskeleton. These biological composites are organized with both inorganic and organic components in intricate structures. The mineral components enhance strength, while the organic components add ductility Paul et al. [8] examined the properties, technology, environmental benefits, and market dynamics of bio-composites. They identified a significant non-food market for fibers and resins derived from crops. The study highlighted various factors affecting bio-composite performance, including fiber architecture and the fiber-matrix interface. Specifically, fiber architecture, which includes aspects like fiber geometry, orientation, packing arrangement, and volume fraction, influences many mechanical properties of composites. Among these, fiber volume fraction is particularly critical, as it is directly proportional to mechanical properties. Additionally, the fiber-matrix interface is essential for composite performance, as it transfers applied loads to the reinforcement through shear stresses at the interface.Sarah [9] conducted a study on the mechanical properties of biocomposites. They used renewable resources that biodegrade in anaerobic environments to create a biopolymer for a new generation of composites. After their service life, these biocomposites can serve as fuel or feedstock. The developed materials aim to replace less eco-friendly structural and non-structural materials in construction. Hemp fabric was selected for its high modulus of elasticity compared to other natural fibers like flax and jute. The hemp fabric was derived from cotton or wood pulp, and polyhydroxybutyrate, produced by microbes, was chosen as the matrix material based on preliminary studies. Tensile specimens were prepared and tested according to ASTM D638, “Standard Testing Method for Plastics Tensile Properties.” Measurements included modulus of elasticity, maximum strength, percentage elongation, and Poisson’s ratio. The study found that the mechanical properties of Hemp/Cellulose Acetate and Hemp/Polyhydroxybutyrate composites are comparable to structural lumber and exceed those of plywood. However, the biocomposites' moduli of elasticity are lower than those of lumber and plywood parallel to the grain. As a result, the design of hemp biocomposite components is expected to be controlled by deflection limits due to their low modulus of elasticity. Chang-Kyu Lee et al. [10] investigated the development of a high-strength biocomposite material by plasticizing cellulose diacetate (CDA) and incorporating kenaf fiber. Both the matrix and the fibers used in this study were cellulose-based. Kenaf, a cellulose-rich plant primarily cultivated in Southeast Asia, is cost-effective to harvest. To enhance the fiber density and improve compatibility with CDA, the kenaf fibers were treated with a polyvinyl alcohol (PVA) solution. This treatment increased the kenaf content in the CDA matrix by nearly 50%. The higher fiber content led to improvements in the modulus, tensile strength, and glass transition temperature of the CDA composite.Kurahatti et al. [11] explored the effects of incorporating nano-sized ZrO2 fillers into epoxy resin, finding that this modification enhanced both the flexural modulus and flexural strength of the epoxy. Chaudhary et al. [12] have developed bio-composites and hybrid composites utilizing natural fibers such as jute, hemp, and flax, reinforced with an epoxy thermoset matrix using the hand lay-up technique. Experimental tensile tests revealed that the inclusion of natural fibers significantly enhances the tensile strength of the bio-composites compared to the pure epoxy polymer. Among the composites tested, the hybrid composite comprising jute, hemp, flax, and epoxy exhibited superior tensile strength, Young's modulus, and percentage elongation compared to other combinations. The observed improvement in tensile strength suggests robust bonding between the natural fibers and the epoxy matrix.Vinod et al [13]. reviewed various aspects of eco-friendly biobased materials and concluded that biofibers, derived from various renewable sources, serve as a potent raw material for reinforcing composites, making them suitable for industrial, commercial, and biomedical applications.

In recent decades, polymer nano-composites have become a highly promising and compelling class of materials due to their remarkable ability to enhance the mechanical and corrosion resistance properties of composites [14]. These improvements have significant implications for various industries, including construction, cosmetics, medical and biomedical sciences, food packaging, and many others. One particularly active and dynamic research area focuses on nanocomposites that incorporate a synthetic polymer matrix reinforced with nano-sized fillers. This work aims to improve the properties of natural fiber-reinforced polyester resin composites by incorporating nano clay into the matrix. A composite material consisting of coir and jute fiber reinforced polyester resin with the incorporation of nano clay was developed separately, and mechanical property tests were performed on standard samples to evaluate their performance.

COMPOSITE PREPARATION METHODOLOGY

Jute and coir fibers as shown in Figure 1 were used to create laminates through a compression molding process. Prior to fabrication, the fibers were treated by soaking them in a Sodium Hydroxide (NaOH) solution. After thorough washing and drying, the fibers were dipped in NaOH again for one hour, then washed and dried at 50°C.

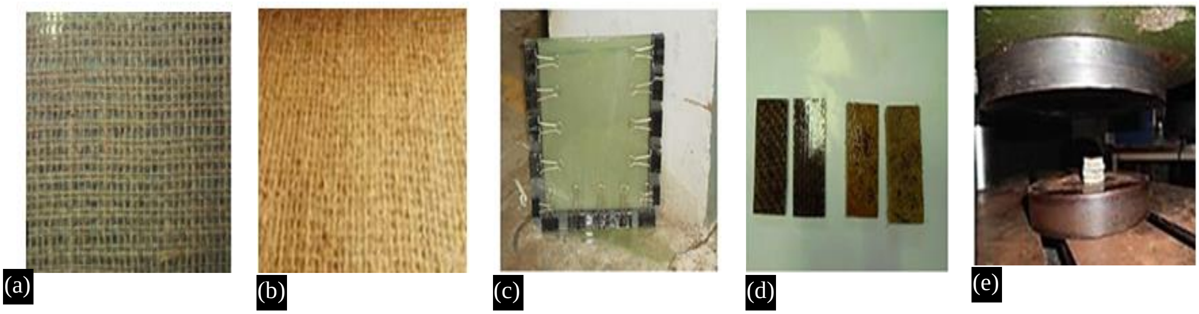

Figure1. (a) Jute fibre (b) Coir fibre (c) Moulding (d) Composite laminates (e) Specimen Testing

These treated fibers were then utilized in the laminate fabrication process. General polyester resin was used in conjunction with an accelerator (Cobalt Napthanate) and a catalyst (Methyl Ethyl Ketone Peroxide, MEKP), both serving as hardeners. Garamite nano clay was incorporated into the resin at an optimal concentration of 3%. The Garamite was treated with epoxy silane coupling agent to improve its compatibility with the polyester resin. The modified Garamite was gradually added to the polyester resin while continuously mixing. This mixture was stirred mechanically for 3 hours and then degassed in a vacuum oven to remove air voids. The laminates were created using a compression molding technique. The jute and coir laminates were cut into 300mm x 300mm pieces, with a fiber-to-resin ratio of 1:3. Two layers of fiber, each weighing 105g, were combined with 630g of general polyester resin. Laminates were prepared with and without the addition of nano clay. The accelerator and catalyst were added at 1.5% of the total resin weight.

EXPERIMENTAL RESULTS AND DISCUSSION

Compression Test

The compression test specimens were prepared according to ASTM D 695 standards, with dimensions of 13mm x 13mm x 3mm. The tests were performed using a Universal Testing Machine with a maximum capacity of 400 kN. This procedure measures the compressive strength of each specimen. The results obtained are shown in Table 1 and 2.

Table 1. Compressive strength values of jute reinforced biocomposite specimens

Sl. no.	**Without nano clay addition**		**With nano clay addition**	
	Peak load(kN)	***Compressive strength (kN/mm^2)***	***Peak load(kN)***	***Compressive strength (kN/mm^2)***
1	17.820	0.105	18.120	0.135
2	16.060	0.095	16.460	0.115
3	16.620	0.098	16.980	0.128

Table 2. Compressive strength values of coirreinforced biocomposite specimens.

Sl. no.	**Without nano clay addition**		**With nano clay addition**	
	Peak load(kN)	***Compressive strength (kN/mm^2)***	***Peak load(kN)***	***Compressive strength (kN/mm^2)***
1	6.560	0.039	6.920	0.041
2	6.380	0.038	6.380	0.038
3	5.8	0.034	6.980	0.041

Table 3. Tensile strength values of jute reinforced biocomposite specimens

Sl. no.	**Without nano clay addition**		**With nano clay addition**	
	Peak load(kN)	***Tensile strength (kN/mm^2)***	***Peak load(kN)***	***Tensile strength (kN/mm^2)***
1	2.060	0.026	3.2	0.037
2	2.700	0.035	3.5	0.042
3	2.56	0.033	3.64	0.043

Table 4. Tensile strength values of coir reinforced biocomposite specimens

Sl. no.	**Without nano clay addition**		**With nano clay addition**	
	Peak load(kN)	***Tensile strength (kN/mm^2)***	***Peak load(kN)***	***Tensile strength (kN/mm^2)***
1	0.74	0.008	0.9	0.010
2	0.7	0.007	0.96	0.011
3	0.86	0.009	0.92	0.011

Table5. Impact strength values of jute reinforced biocomposite specimens

Sl. no.	**Without nano clay addition**	**With nano clay addition**
	Energy absorbed (J)	***Energy absorbed (J)***
1	0.6	0.6
2	0.5	0.7
3	0.6	0.7

Table6. Impact strength values of coir reinforced biocomposite specimens.

Sl. no.	**Without nano clay addition**	**With nano clay addition**
	Energy absorbed (J)	***Energy absorbed (J)***
1	1.5	2
2	1.8	2
3	2	1.8

Tensile Test

The tensile test specimens were prepared following ASTM D3039 standards, with each specimen measuring 300mm x 25mm x 3mm in cross section. The tests were conducted using a Universal Testing Machine with a maximum capacity of 400 kN. A constant gauge length of 150mm was maintained for all specimens during the experiment. This testing procedure provides the tensile strength for each specimen. Table 3 and 4 presents the peak load and tensile strength values recorded during these tensile tests.

Impact Test

The impact test specimens were prepared in accordance with ASTM D 4812 standards, with dimensions of 65mm x 12mm x 3mm. The tests were conducted using an Izod Impact Testing Machine with a capacity of 25 Joules. This test measures the amount of energy absorbed by each specimen. Results are presented in Tables 5 and 6. It was observed that jute-reinforced composites containing nano clay exhibited higher energy absorption compared to those without nano clay.

Nano clay composites have shown promise in improving material strength and stiffness when compared to other common nanomaterials like carbon nanotubes, graphene, and silica. However, factors such as material type, amount of nanomaterial, and manufacturing process influence the overall performance. Nano clay's layered structure contributes to its ability to enhance material strength and toughness. Additionally, it's often lighter than metal-based materials. The nano clay composites have advantages in terms of strength, cost, and environmental impact, and the best choice of nanomaterial depends on the specific needs of the application. Nano clay can make natural fibers stronger without using more material. This can lead to lighter products and save money. While synthetic fibers are often stronger, they're also more expensive. Nano clay offers a balance, improving natural fibers without the high cost. Other tiny particles like carbon nanotubes can also help, but they're usually even more expensive than nano clay.

Nano clay can make materials stronger initially, but its performance over time can be affected by factors like weather, pollution, and constant use. These conditions can weaken the material and the bond between the clay and the surrounding material. To improve the material's lifespan, it's crucial to use a durable polymer, strengthen the bond between the clay and polymer, and protect the material with a coating.

STATEMENTOFNOVELTY

This research introduces a novel method of incorporating nano clay into coir and jute reinforced bio-composite materials. The integration of nano clay into coir and jute fibers significantly improves the tensile strength, flexural strength, and impact resistance of the bio-composite material. This enhancement is attributed to the nano clay's ability to fill the micro-voids and improve the interfacial adhesion between the natural fibers and the polymer matrix. The addition of nano clay provides better thermal stability to the bio-composites. This makes the material suitable for applications where higher thermal resistance is required, expanding the potential use cases of coir and jute reinforced composites. Nano clay improves the barrier properties of the bio-composite materials, making them more resistant to moisture and gases. This property is crucial for applications in packaging and construction, where moisture resistance is critical factor. Utilizing coir and jute, which are biodegradable and renewable resources, along with nano clay, aligns with the principles of sustainability. This novel approach reduces the reliance on synthetic fibers and non-biodegradable materials, contributing to environmental conservation. The incorporation of nano clay into natural fiber composites is a cost-effective solution compared to other reinforcement materials. This makes technology accessible for widespread adoption in various industries, including automotive, construction, and packaging.

CONCLUSIONS

The introduction of nano clay into coir and jute reinforced bio-composite materials represents a significant advancement in the field of sustainable materials. This novel approach not only enhances the mechanical and thermal properties of the composites but also aligns with global sustainability goals. The results showed that the addition of clay enhanced the tensile strength, impact energy, and compressive strength of the natural fiber composites. The nano clay provided additional reinforcement to the fibers, leading to improved mechanical performance. Tensile, impact, and compressive tests demonstrated consistent behavior across specimens with added clay. Alongside these improvements, the storage modulus increased with higher fiber loading, attributed to the enhanced stress transfer at the fiber-resin interface. The addition of nano clay also increased the resin mix's viscosity, likely due to stronger interactions between the clay and resin. While the mechanical properties of coir/jute and polyester composites are not as high as those of conventional composites, they surpass those of wood composites and some plastics. These eco-friendly, non-toxic, and cost-effective composites offer a promising alternative for various applications. They are suitable for indoor uses such as shelves and partitions, and may also be applicable for outdoor purposes like roofing, drainage pipes, automobile components, and lightweight fishing boats. Further testing is needed to evaluate their hygro-thermal and weather resistance properties to fully assess their suitability for outdoor use.

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