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Evaluating Physical and Mechanical Properties of Coco Peat/Nano Clay/Nano Titanium Carbide Nanocomposite

Seenivasan Soundararajan[1], Sellamuthu Palani[2], Kannakumar Kanagaraj[3], Saravanan Rudrakoti[4], Nanthakumar Sivasamy[5], Gunasekaran Karuppam Palayam Nanjappan[6], Girimurugan Ramasamy[7*] and Ramkumar Rajagopal[8]

[1]*Department of Mechanical Engineering, Rathinam Technical Campus, Coimbatore, Tamil Nadu, India*
[2]*Department of Mechanical Engineering, Vinayaka Mission's Kirupananda Variyar Engineering College, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India*
[3]*Department of Mechanical Engineering, Shree Venkateshwara Hi-Tech Engineering College, Erode, Tamil Nadu, India*
[4]*Department of Robotics and Automation, Rajalakshmi Engineering College, Chennai, Tamil Nadu, India*
[5]*Department of Mechanical Engineering, PSG Institute of Technology and Applied Research, Coimbatore, Tamil Nadu, India*
[6]*Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamil Nadu, India*
[7]*Department of Mechanical Engineering, Nandha College of Technology, Perundurai, Tamil Nadu, India*
[8]*Department of Mechanical Engineering, K. Ramakrishnan College of Technology, Tiruchirappalli, Tamil Nadu, India*

***Correspondence to:**
Girimurugan Ramasamy
Department of Mechanical Engineering,
Nandha College of Technology,
Perundurai, Tamil Nadu, India.
E-mail: dr.r.girimurugan@gmail.com

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Abstract

The aim of this is to create and evaluate nanocomposite materials made from coco peat agricultural waste for use in future structural applications. The composites were manufactured by compression molding. The manufacturing process began with a 4-hour soak of coco peat filler in a 5% NaOH (sodium hydroxide) solution. Nano titanium carbide (TiC) (NT) and nano clay (NC) concentrations were investigated for their influence on the physical-mechanical characteristics of a nanocomposite based on coir. Loading with 6 wt.% NT and 4 wt.% NC significantly enhanced mechanical properties. The incorporation of different nanoparticles decreased both the composite's swelling in thickness and its absorption of water. After 21 days, water absorption was reduced by 6, 9, and 18% respectively, when NT was included at 2, 4, and 6 wt.%. The highest concentration of NC filler (4 wt.%) resulted in a 4.12% increase in moisture content, while the lowest concentration (2 wt.%) resulted in a 5.24% decrease in water uptake and the highest concentration (3 wt.%) resulted in a 9.14% decrease. The effects of NT and NC on increasing adhesion due to interactions between coco peat and polymer matrices.

Keywords

Nano titanium carbide, Agro waste, Nano clay, Tensile strength, Physical properties, Nanocomposite

Introduction

There have been recent shifts in the composite industry that can be attributed to the increased use of nanomaterials and cellulose fibers. The first is incorporating nanoparticles into composites to boost their performance. The replacement of high-tech fibers in structural composites with cellulose fibers is central to the secondary aim, which is the creation of eco- friendly materials [1, 2]. There are a number of benefits to using natural fibers to reinforce polymers, the primary one being the cost-effectiveness with which mechanical improvement can be achieved. There is tremendous hope that composites made from natural fibers can help us solve some of the environmental problems of the future. They are renewable, inexpensive to use, and biodegradable, all of which contribute to a cleaner world [3, 4]. Natural fiber reinforcing, however, has very few applications since the organic matrix of polymers is incompatible with natural materials and their interfacial bonding is poor. Therefore, the dispersibility of the constituents is low, and the properties of the resulting composites are diminished. Due to their low standard of quality, recyclables have limited applications. These recyclable materials are combined with epoxy resins to make composites with improved properties for use in structural applications [5].

When coconut fiber is harvested, the fibrous byproduct known as coco peat is typically burned or thrown away as waste. When fiber is extracted, it produces two tons of pith. It is believed that India stores 10 x10^6 metric tons of coco peat in its southern areas, while another 7.5 x10^5 tons is generated annually across the country [6, 7]. Greenhouse gases are increased when burned agricultural waste. Polluting lignans and phenolic chemicals seep out of coco peat and seep into water and soil. The puffiness of it makes transport difficult. Therefore, new approaches to discarding coco peat are required. This means that for countries that produce coco peat, it is crucial to find efficient ways to increase the value of the material [8, 9]. Utilizing coco peat properly can produce a product that is both recyclable and good for the environment. Coco peat has many applications, including wastewater treatment by adsorbing reactive colors, mushroom cultivation substrate, soil replacement, and many others [10]. Coco peat contains cellulose, which has piqued researchers' attention because of its potential as a structural component in high-tech, lightweight materials. Coco peat's high-water absorption and preservation is a major drawback when employed in polymeric products [11].

The low water resistance quality of the composite is due to the hydrophilic property of coco peat, which reduces their durability and efficiency [12]. Because of its unusual molecular structure, lignocellulosic biomass has a high moisture content, which leads to poor matrix-to-filler adhesion [13, 14]. Lignocelluloses that have been treated with an alkaline solution have a lower moisture absorption rate and a higher filler-matrix interaction. Authors [15] examined composites of polyester bonded with jute fiber and wood dust. Epoxy resin was used to replace cementing elements that were removed during alkali treatment. The mechanical properties of the composite were greatly improved as a result of the increased strength of the binding between the fiber bundles and the matrix. Researchers [16] studied the impact of NaOH on the mechanical characteristics of PALF/Kevlar composites. The treated materials showed improved interlaminar shear strength as compared to untreated fiber composite samples. Authors [17] examined the mechanical properties of epoxy, nano silica, and coir fiber composites. The results showed that the mechanical parameters of the fibers were improved with alkali treatment, resulting in increased stiffness and strength in the composite.

Using nanoparticles to strengthen the durability of composites manufactured in the manufacturing industry could lead to the development of novel products with improved value and performance. There are a number of nanomaterials available today that are utilized for these purposes; examples include NC and NT [18, 19]. Non-toxic, stable, cheap, and simple to obtain, these nanomaterials also boast a high aspect ratio, a large surface area, and a layered structure. Fine-grained, sheet-shaped particles are the most common type of NC, which are aluminum silicates found in nature. Phyllosilicates are the name given to the hydroxide silicate minerals that have a sheet structure. There is a vast variety of uses for the inexpensive, abundant, and ecologically friendly material clay [20, 21]. These minerals have attracted a lot of interest due to their numerous useful applications in fields as diverse as geology, agriculture, construction, architecture, and industry. Soil, underground fluid, sediment, and industrial pollution can all be decontaminated using this method, making it an attractive alternative. NT has the ability to increase the mechanical characteristics of polymer matrices while also being inexpensive, non-toxic, and cytotoxic. It also exhibits good heat resistance [22]. Mechanical performance was enhanced by the incorporation of nanofillers, which boosted stress transmission at the contact. Nanomaterials' properties can be enhanced without requiring any adjustments to the manufacturing procedure [23]. Nanomaterials also outperform high-performance materials in terms of heat resistance and recycled content. Authors [24] examined the effectiveness of NS-containing insulating paper. The mechanical properties of the composite samples were found to be enhanced by the addition of 4% silica filler, as discovered by the authors. Authors [25] studied hybrid composites made of cocoa pod husk filler made of epoxy and natural fibers. The researchers showed that the interfacial bonding of the lightweight materials was enhanced by the addition of a filler at 3 wt.%. Researchers [26, 27] examined the results of testing composite samples with glass fiber and NT fillers. Compressive and flexural strengths were shown to rise by 34% and 38%, when NT was added at 6 wt.%. The literature includes discussions of the relevance of different nanofiller insertion weight ratios.

Hybrid composites made from agri-waste by-products like coco peat and nanofillers like clay and TiC have not been previously created, to the authors' knowledge. These conditions prompted the current investigation. The objective of this analysis is to create a hybrid epoxy out of agro-waste, NC, and nanoscale TiC and assess its physical, mechanical, and morphological qualities. The aforementioned objectives were accomplished by employing conventional compression molding techniques to make the composites. The materials were put through rigorous ASTM testing after manufacturing.

Materials and Method

Materials

To eliminate any bacteria or germs that may have made it onto the outer fibers and soaked the pieces in filtered water for a day after collecting them. After being dried in an oven at 75 °C for 24 h, the moisture content of the fine particles was less than 5%. To get rid of wax and other pollutants from the reinforcing filling, the cleaned coir portions were soaked in 5% NaOH solutions for 4 h. After being alkalized, the fillers spent 120 min curing in a micro-oven at 56 °C. Because of chemical processing, natural fillers may now be used in composite manufacturing.

NC, or sodium montmorillonite is a kind of clay that has a relatively low density of just 1.65 g/cm^3 when in its solid form. The resulting NC is 110 nm in size and has a melting point of 1710 ˚C. This NT is similarly solid and completely grey in color. The resulting NT has a melting point of around 1670 ˚C and a size of 100 nm. LY 556 epoxy resin and HY 951 hardener.

Composite fabrications

Epoxy resins have been used to bind together coco peat granules (40 wt.%) that have been treated with an alkaline solution (The resin-to-curing-agent ratio is 10:1). These prices were the result of a great compromise between efficiency and cost, and they were obtained from a variety of professionally produced algorithms. Then, using the parameters listed in table 1, coco peat doped with NC and NT was included into the mixes for 10 min. Compression molding at 180 ˚C and 90 bar for 10 min produced the composite plate. The composite manufacturing process is depicted in figure 1 using schematic diagrams.

Table 1: Fabrication of composites using a composition.

Notations of sample	Epoxy (Wt.%)	Coco peat (Wt.%)	NC (Wt.%)	NT (Wt.%)
S1	100	0	0	0
S2	60	40	0	0
S3	58	40	0	2
S4	56	40	0	4
S5	54	40	0	6
S6	58	40	2	0
S7	56	40	4	0
S8	54	40	6	0

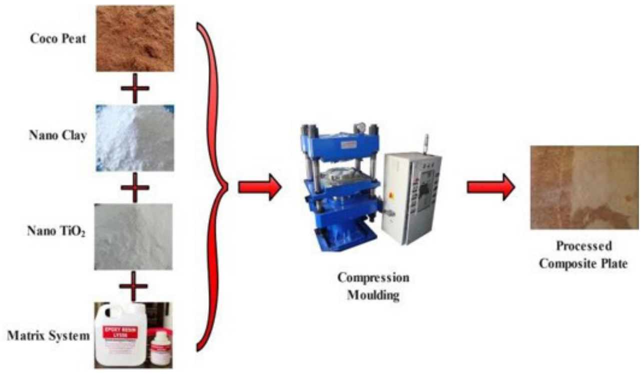

Figure 1: Coco peat, NT and NC based hybridized composite fabrication.

Properties of materials

Physical properties

Following the protocols detailed in ASTM 570, a sample of a hybrid composite made from coco peat, NC, and NT was soaked in distilled water for 21 days. The hybrid composites were dried out by baking them at 55 ˚C for 24 h before being weighed (5.32 g) on a precision scale and used in the experiment. The composites were weighed, then transferred to a holding tank filled with water. Composite specimens were removed from water baths and wiped off with tissue paper once daily. The amount of water absorbed by the composite samples was determined by weighing them. The weight of composite specimens was tracked on a regular basis until saturation with water was reached. After 14 days in water, all of the composite materials used in this experiment were completely saturated. Since the proportion of water absorbed did not improve after day 14 of the current study. To determine how much water is absorbed, apply equation 1 [27].

$$Moisture\ absorption = \frac{M_w - M_d}{M_d} \text{ x } 100 \qquad (1)$$

Where the initial dry mass (M_d) is subtracted from the final wet mass (M_w) to determine the density of the substance.

The following equation was also used to determine the thickness swelling in percentage:

$$Thickness\ swelling = \frac{T_w - T_d}{T_d} \text{ x } 100 \qquad (2)$$

Where T_d is the dry specimen's starting thickness and T_w is the wet specimen's ending thickness.

Mechanical properties

The tensile strength of a material was measured by subjecting it to various levels of tension. The results of a tensile test can be used as a guide for selecting a specimen for use. The flexural strength of a material is tested to see how far it can be bent before breaking. It also specifies the strain, stress, and stress-strain behavior of the material under flexure. The behavior of composites is often evaluated using three-point bend tests. The resilience of a material can be evaluated with an impact test. In the course of the test, the samples are tested to extremely high levels of force for brief periods of time. The energy absorption capacity of a substance is determined using this procedure. High impact energy simply indicates pliability and durability. The tensile properties of the produced nanocomposites were measured using a universal testing machine (Instron 3300) that complies with ASTM D 3039 [28]. The bending strength of the material was evaluated through the three-point flexural test method. The pillars took the brunt of the weight. The same universal testing machine was used to conduct the bending test, which was carried out at a rate of 2 mm/min. Synthesized samples were tested for Izod impact tests using the ASTM D 256 method. A durometer was employed to measure the hardness of the composites, and the results were expressed in terms of Shore D hardness. Each specimen's impact and hardness values were calculated using the sum of three separate measurements.

Results and Discussion

Physical properties

Water absorption

One of the most important considerations in laminate fabrication for structural purposes is the moisture of the material. Due to the fact that it modifies the mechanical characteristics and structural rigidity of the composites. After 21 days of submersion in water, the nanocomposites' observed moisture absorption changed for each nanoparticle. Increases in the proportion of organic lignocellulosic components and the duration of soaking both lead to higher moisture contents in the final composites. The hydrophilic property of coir, caused by hydrogen bonding between the hydroxyl groups on its surface, gives epoxy/coir hybrids better water absorption. Coir additives' hydrogen atoms can be accessed via capillary action due to the organic lignocellulosic materials' high number of porous tube structures. Natural lignocellulosic materials, resin dispersion, and the coir-epoxy interface are all viable pathways for water absorption by highly composite materials. This indicates that the interfacial bonding between components is critical for water absorption, in addition to the hydrophilic qualities of coco peat and resin.

All of the manufactured composites tested in this study had the same time to saturation. However, pure epoxy is so water resistant that it only absorbs about 0.3% of its weight in moisture [29, 30]. It was found that after being treated with NaOH, the water absorption of the materials decreased in contrast to the epoxy and coco peat. Coir's water uptake was restricted because the concentration of -OH groups might be lowered by isomerizing NaOH and -OH. Additionally, the increased interfacial bonding of epoxy hybrids reduced voids in compatibilizer-treated hybrids, hence limiting the infiltration of water molecules into the final product. After 21 days, water uptake was reduced by 5.165, 8.84, and 18.40%, respectively, when NT was incorporated at 2, 4, and 6 wt.%. This is due to the fact that the NT particles operate as water-resistant materials with a wide surface area by penetrating into the composite coating to increase interfacial bonding, hence limiting blank spaces and the passage of water particles. While additions of NC filler at 2 and 4 wt.% reduce water absorption by 5.39 and 9.29%, correspondingly, agglomeration of NC filler at 6 wt.% increased moisture content by 4.27% (Figure 2).

Thickness swelling

Figure 3 displays the thickness variation of the material analyzed after being submerged in filtered water for 21 days. The created composite expands in thickness as it absorbs water, following the same trend as the moisture content. The composites made with no discernible nanoparticles (NT or NC) expanded at the fastest rates in terms of thickness. Thickening was mitigated by the incorporation of nanoparticles for the same reasons discussed in the section on water absorption. When a higher concentration of nanofiller causes the swelling thickness to decrease. Nanofillers, when paired with a compatibilizer, greatly improve the mechanical properties and water absorption rate of the materials. This may be due to the hydrophobic nature of the matrix, fillers, and reinforcement. Results from the mechanical test indicated that hybrid composites utilizing nanofiller and organic reinforcements in a polymer might be used to improve the mechanical qualities of a variety of housing and closure designs while still maintaining their lightweight characteristics. There is a growing demand for greener, more environmentally friendly construction materials, and hybrid nanocomposites could be an important part of the solution to this problem.

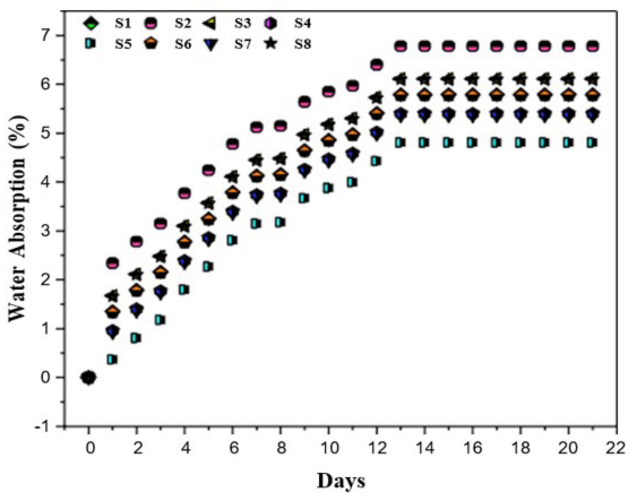

Figure 2: Hybrid composites made from epoxy, coco peat, NT, and NC show interesting moisture absorption properties.

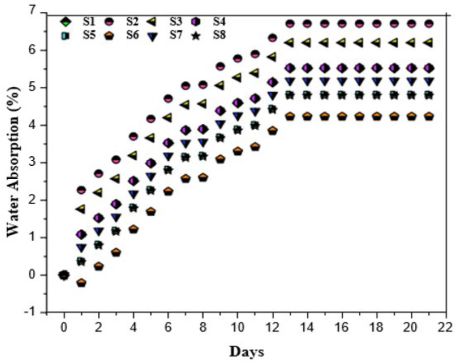

Figure 3: Behaviour of thickness swelling in hybrid composites based on epoxy, coco peat, NT, and NC.

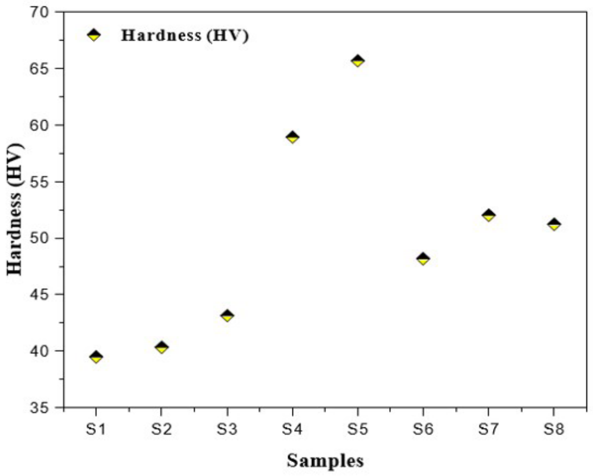

Figure 4: Hardness properties of various hybrid composites.

Mechanical properties

Hardness

Figure 4 displays, under both NT and NC loads, how the materials investigated fare in terms of hardness. Composites made of epoxy and coir are 3.92% harder than epoxy alone. Increased coir stiffness and less polymeric chain mobility may account for the increase in hardness of the resultant composites. When natural fibers were included into the hybrid, the polymer mobility of a hard interaction among coco peat and the epoxy was diminished, making the hybrid brittle under stress. The addition of NaOH caused a little increment in toughness, from 40.35 to 43.14 shore D. The addition of NT at 2, 4, and 6 wt.% increased the toughness of epoxy/coir composites by 2.15, 4.84, and 5.3928%, respectively. NC increased the hardness of epoxy + coir composites by 1.12, 2.46, and 4.26% at 2, 4, and 6%, respectively. It would have been possible to pinpoint the cause of the increasing difficulties much earlier. Dispersion of nano-better clay allows for more efficient stress transmission at the boundary, which is responsible for the improved characteristics of the materials. Due to the fact that NC is more hydrophilic than NS, it results in inferior fiber-to- matrix contact, NS-based nanocomposites exhibited better performance.

Flexural strength

Figure 5 shows that the bending quality of the investigated materials increased with increasing NT and NC concentration. When flexural strength was measured, the epoxy/coir composites without NaOH pre-treatment ranged from 52.39 to 59.48 MPa. The hybrids' flexural strength is diminished due to fiber aggregation when the matrix material bonded together the coir fillers. Residual strains in the organic fibers resulted from the expansion of the coco peat and the contraction of the epoxy caused by inadequate interfacial bonding. A higher percentage of organic cellulose fibers means more likely void generation during production, which dampens bending capabilities. Including NaOH in the pre-treatment process for epoxy/coco peat hybrids increased their flexural strength. The epoxy/coir hybrids with NT added at 2, 4, and 6 wt.% showed similar tension and bending behaviors improvements of 14.52, 23.65, and 36.41%, respectively. The flexural strengths of epoxy and coir composites were improved by 9.21 and 26.32%, respectively, when NC was added at 2 and 4 wt.%. It possesses a strong fiber-matrix interfacial connection, nanofillers particles can be dispersed throughout the fiber and material interface with minimal clumping.

Flexural strength was reduced when low NT levels were added to an already high NT proportion (6 wt.%). The flexural modulus of the materials under NT and NC loads is also shown in figure 5. The flexural modulus of unprocessed epoxy + coco peat composites increased from 208 MPa to 628 MPa. The flexural modulus of epoxy + coco peat composites was significantly increased after chemical treatment, in comparison to that of untreated composites. The elastic strength of epoxy + coco peat hybrid was improved by 12.24, 20.25, and 34.89% when NT was added at 2, 4, and 6 wt.%, and by 13.65, 30.241, and 33.581% when NT was added to epoxy/alkaline-processed coir hybrids. The elastic strength of the manufactured samples rose by 6.21 and 19.25%, respectively, when NT was added at 2 and 4 wt.%. Filler improved the hybrid's performance by improving interface contact with the matrix and reinforcement by spreading nano clay particles uniformly over the blended surface. It was found that the elastic modulus may be improved by 20% for NC and by 28% for NT simply by adding 6 wt.% of filler components. However, epoxy matrices include water and -OH molecules, which break down the composites over time. Particle aggregation lowers the flexural modulus of materials with a high NT content (6 wt.%). This is because, at greater weight percents, epoxy and nanomaterials have weak surface contacts. When the NT content of an epoxy is increased, the nanoparticles become unevenly distributed, which decreases their surface area and, in turn, their ability to interact, leading to a less uniform cross-link density.

Impact strength

Figure 6 shows the impact resistance of the manufactured nanocomposites. The absence of NaOH resulted in a reduced impact resistance of 12.39 kJ/m^2 for the epoxy/coir composites. Micro-fractures may form at the location of impact and rapidly propagate throughout the hybrid if the coir and polymeric matrix are not in contact with one another. The nanocomposite's resilience is diminished due to the prevalence of these microscopic fissures. Since the micro-crack always started in the coco peat matrix rather than the interface, increasing the impact strength of composites by incorporating a NaOH pre-treatment was not successful. The resultant laminate has poorer Izod strength qualities due to the use of coir, which is much more delicate than resin. Impact strength was also diminished due to the introduction of nanomaterials (NT or NC). Reducing the impact energy and causing stress concentrations that can cause cracks, NT and NC particles in the resin supply. Decreased impact resistance may also be due to the epoxy matrix chain strengthening, which reduces the material's ability to absorb impact force. As the loading of nanofiller (NT and NC) increased, the mechanical properties of the material degraded because cluster formation prevents the load from being distributed uniformly throughout the mate-

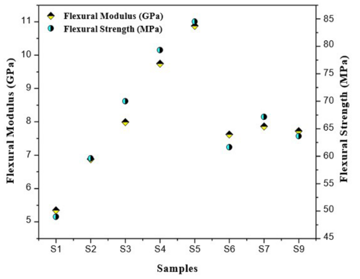

Figure 5: Flexural modulus and strength of hybrid composites based on epoxy, coco peat, NT, and NC.

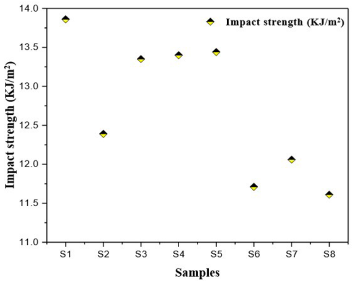

Figure 6: Impact resistance of hybrid composites based on epoxy, coco peat, NT, and NC.

rial. The above result may be understood to suggest that the ductility of epoxy decreases and the risk of microcrack development increases with increasing percent loading of hybrid composites. Since NT increases the brittleness of composites, increasing the amount added to a material reduces its impact strength.

Tensile strength

Tensile characteristics of the materials under NC and NT loads are shown in figure 7. Coco peat hybrids saw their tensile strength decrease from 64.62 MPa to 54.24 MPa when the coco peat content was 40%. It's possible that the low tensile strength was caused by poor adhesion between the coco peat and the matrix material. The natural fabrics' unsteady structure also contributed, as they were less able to bear the tension transferred from the polymers. Aggregation of organic fibers and polymer dewetting at the interphase can also account for the reduction in tensile strength. The tensile strength of the produced materials was improved with NaOH processing compared to the untreated materials. The results can be interpreted as showing that the epoxy/coco peat interaction is highly effective after being activated by NaOH. As a result of hydrogen bond creation between the hydroxy groups on the coco peat surface and the reaction liquid, interfacial bonding was produced. The nanocomposites' tensile strength raised by 32, 43.26, and 53.48% after 2, 4, and 6 wt.% NT was added. The optimum dispersion of NT in resin may be responsible for this enhancement, since it increases the surface area accessible for interactions with NT and the polymer matrix. When added to composites, NC increased their tensile strength by 21.48 and 35.96% at 2 and 4 wt.%, respectively. Improved binding between the epoxy and the fiber may account for the increased tensile properties and pliability brought about by the incorporation of nanofillers. The nanofillers' surfaces act as a joining linkage between the reinforced elements and the pattern. When loads or pressures are applied, the onset of fracturing or fracture can be postponed by transferring the stress from the matrix to the fibers. The conclusion that coir epoxy composites benefit from the application of nanofiller may be reached due to the fact that nanofiller enhances physical adhesion at the interface between the components and leads to effective stress transfer under load. Adding 6% NC reduced the tensile strength by 22.6%, although the high aspect ratio and homogeneous dispersion of NC grains in the epoxy likely accounted for the improved strength of the coco peat and epoxy materials. The decrease in tensile characteristics is likely due to the fact that producing NC films severely limits nanoparticle dispersion inside the polymer matrix.

Figure 7 displays the tensile modulus of the factory-made samples. When added to an epoxy composite, coco peat boosted the material's modulus from 2.62 to 3.72 GPa. Examined composites exhibited increased tensile modulus, which may be related to the increased rigidity brought about by the coir filler's greater stiffness over the epoxy matrix. Greater elastic strength in epoxy/coco peat hybrids after alkalization may point to improved coir dispersion and stronger fiber-matrix interaction. Increases of 9.25, 16.54, and 24.32% were seen in the tensile modulus of nanocomposites after NT was added at 2, 4, and 6 wt.%, respectively. Because NT are stiffer than some of the other composite ingredients, treated composites exhibit enhanced properties. In addition, the enhanced adhesion and reduced mobility of polymeric chains led to a dramatic enhancement of mechanical properties. However, at 2 and 4 wt.% NC was added to nanocomposites, the elastic strength increased by 7.65 and 14.25%. When adding NC at 6 wt.%, the tensile modulus dropped by 9.20%. Matrix grains may be removed, and the composite's strength increased due to the constraints of nano clay clusters and epoxy resin. Aggregation of the NC layer is likely to depend on the drop in tensile modulus. NT-filled hybrid nanocomposites have a somewhat higher tensile strength than those without it. This is due to the increased potency of the effects, the increased dimension ratio, the enhanced interfacial separation, and the platelet structure. As a result, nanocomposites experience far less tensional stress. In comparison to unfilled coir nanocomposites, the tensile properties of NC-filled coco peat hybridized nanocomposites are much reduced because of incompatibility between the hydrophilic NC components and the hydrophobic epoxy polymer matrix. This prevented the dispersion phase and epoxy matrix from interacting, which would have resulted in significantly higher tensile stress.

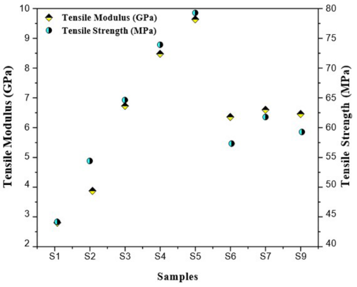

Figure 7: Modulus and tensile strength of epoxy-coco peat-NT-NC hybrid composites.

Conclusions

This research shows that hybrid composites consisting of epoxy and agricultural waste may be used (coco peat). NT and NC were two nanofillers studied for their effects on nanocomposite mechanical, physical, and morphological properties.

- After 21 days, water absorption and permeation decreased by 5.16, 8.84, and 18.4%, respectively, when NT and NC were included at 2, 4, and 6 wt.%. In addition to enhancing interfacial bonding and diffusing inside the composite coating, Nanoparticles can also act as water-resistant materials due to their huge surface area.
- The hardness rose from 40.35 to 43.14 shore D when NaOH was added. At 2, 4, and 6 wt.%, NT improved toughness by 2.15, 4.84, and 5.39%, correspondingly, in epoxy/coir materials. Hardness increased by 1.12, 2.46, and 4.26% when NC was added to epoxy/coir hybrids at 2, 4, and 6 wt.%, respectively.
- The tensile strength increased by 33, 43.29, and 53.62% after adding 2, 4, and 6 wt.% NT to nanocomposites, respectively. This improvement may have resulted from

the incorporation of silica nanoparticles into the resin in an optimal fashion, which increases the surface area accessible for interactions between NT and the polymer matrix. When NC was added at 2 and 4 wt.%, the composite's tensile strength increased by 21.64 and 35.49%, respectively.

Acknowledgements

None.

Conflict of Interest

None.

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