Nano World Journal

https://doi.org/10.17756/nwj.2023-s4-020

Research Article

Open Access

Development and Mechanical Properties of Jute-banana Hybrid Composites with Effect of Alkali Treatment and Polylactic Acid Coating

Naveen Reddy Challabotla[1,2*] and Suresh Kumar Jyothula[1]

[1]*Department of Mechanical Engineering, Jawaharlal Nehru Technological University, Hyderabad, Telangana, India*

[2]*Department of Mechanical Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, India*

***Correspondence to:**
Naveen Reddy Challabotla
Department of Mechanical Engineering,
Jawaharlal Nehru Technological University,
Hyderabad, Telangana, India.

Department of Mechanical Engineering,
VNR Vignana Jyothi Institute of Engineering and Technology,
Hyderabad, Telangana, India.
E-mail: chnaveenreddy316@gmail.com

Received: September 15, 2023
Accepted: November 21, 2023
Published: November 24, 2023

Citation: Challabotla NR, Jyothula SK. 2023. Development and Mechanical Properties of Jute-banana Hybrid Composites with Effect of Alkali Treatment and Polylactic Acid Coating. *NanoWorld J* 9(S4): S113-S118.

Copyright: © 2023 Challabotla and Jyothula. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY) (http://creativecommons.org/licenses/by/4.0/) which permits commercial use, including reproduction, adaptation, and distribution of the article provided the original author and source are credited.

Published by United Scientific Group

Abstract

Hybrid composites are composed of two or more fiber reinforcement components with distinct properties. The emphasis of this work is the development and analysis of mechanical characteristics such as tensile, flexural, impact, and water absorption behavior of five layered jute-banana fiber reinforced hybrid composites. Jute and banana fibers are alkali-treated and polylactic acid (PLA)-coated. The major goal is to use environmentally friendly treatment and coating to improve the mechanical properties and water absorption behavior of polymer-based hybrid jute-banana composites. The hybrid composites were manufactured using a hand layup approach with a fiber content of 40%. Untreated (JB1), PLA-coated (JB2), NaOH (sodium hydroxide)-treated (JB3), and PLA-coated and NaOH-treated (JB4) hybrid composite laminates were developed. The mechanical and water absorption analysis of surface modified composites were evaluated and compared to those of untreated fibers. ASTM standards are used to test laminates. This study found that the PLA coated, and NaOH-treated sample (JB4) had a 20.56% higher tensile strength than the untreated sample (JB1). The flexural strength of the NaOH-treated and PLA-coated hybrid composite structure (JB4) is 16.7% more than that of the untreated hybrid composite structure (JB1). The PLA coated and NaOH-treated jute/banana fiber reinforced hybrid composite samples (JB4) have 20.63% and 47.6% lower impact energy and water absorption capacity, respectively, than the untreated hybrid composite sample (JB1). These composites are suited for medium-strength applications in the automotive, construction, and packaging industries.

Keywords

Eco-friendly composites, Polylactic acid coating, Hybrid composites, Alkaline treatment

Introduction

Natural fibers are mostly used in variety of cutting-edge applications such as automobile, aerospace, building, packaging, household products, and filtration as a result of environmental and economic progress [1]. This is because of their desirable properties such as low expense and density. It is recyclable, biodegradable and environmentally friendly [2]. Natural fibers have also been found to be superior to synthetic fibers in terms of thermal and acoustic insulation [3]. Another reason these natural fibers are seen as synthetic fiber alternatives is because they are biodegradable, have high tenacity, are CO_2 neutral, have high "specific strength, and have a high modulus [4]. Natural fibers have numerous advantages, but they also have certain downsides. Polymer-based composites' applicability in outdoor and high strength applications is limited by low moisture resistance, poor durability, weak interfacial bonding, and poor thermal stability [5]. To get over

these constraints, the fiber surface was modified to clean it by removing a considerable number of impurities and making it hydrophobic. A few chemical methods that change natural fibers to improve interfacial interaction and hydrophobicity of the fiber and matrix by removing hydroxyl groups are alkali, silane, potassium permanganate, benzoylation, acetylation, acrylate, isocyanate, and sodium chlorite and have been subjected to extensive research to improve their mechanical properties. However, the use of hazardous chemicals in all of these treatments is harmful to both human being health and the natural environment. Researchers have recently become interested in environmentally friendly approaches that are safer or less dangerous than chemical methods. Processing with NaOH has lately gained appeal among scientists as an environmentally friendly approach. Fior et al. [6] investigated the effect of sodium bicarbonate treatment on the mechanical performance of flax-epoxy composites and discovered that it increased their performance. To affect the drawbacks of jute fiber composites, Gupta and Singh [7] used jute fibers that had been altered through alkali treatment and PLA coating. Composites made of coated and treated fibers have the best mechanical, thermal, and water resistance. Yadav and Gupta [8] investigated the effects of different chemical treatments (benzoyl chloride, sodium bicarbonate, and alkali) and polymer coatings on the properties of jute fiber. They discovered that jute composites treated with benzyl chloride after being coated with PLA outperformed untreated composite samples. Sahu and Gupta [9] studied the environmentally friendly treatments and coatings affected the functionality of sisal composites. In terms of tensile and flexural-properties, the coated and treated composites outperformed the untreated sisal composites, however reduced the impact strength. Gunti et al. [10] explored how PLA affects the mechanical and deteriorating properties of natural fiber-reinforced-composites. They discovered that PLA composites with elephant grass fiber reinforcement are more recent and resilient than jute and sisal/PLA composites. Ismail et al. [11] discuss the impact of void content on the tensile, vibration, and acoustic attributes of hybrid bamboo/kenaf fiber reinforced epoxy composites. They discovered that hybrid kenaf/bamboo composites had lower porosity and better tensile, vibration, and acoustic properties. Due to environmental concerns, PLA-based bio-composites are one of the greatest possibilities to replace non-biodegradable petroleum derived products universally. Because these composites have adequate mechanical and thermal qualities, they are a viable alternative for presented non-biodegradable petroleum based products [12, 13]. Kumar et al. [14] investigated the influence of fiber length and porosity on the free vibration and damping behavior of polyester composite beams reinforced with natural fibers. They revealed that increasing the length and void content of the fibers increased mechanical and damping properties. Chemical and environmentally friendly procedures have enhanced the mechanical properties of bio-composites. But, due of their significant performance improvements, these composites are expected to be used in cutting-edge products. Alkali treatment had a substantial influence on the composite materials, resulting in a 2% reduction in tensile strength due to lower lateral strength in the direction of inter-laminar fibers [15]. In contrast to potential, the flexural strength of the composites increased by 3.7% after that alkali treatment, revealing the alkali treatment process's ability to improve the elastic-properties of such composites. The proportions of the composites changed once the water absorption test completed, leading to increased longitudinal and decreased lateral dimensions. Sagar et al. [16] studied how mechanical characteristics could be improved by treating woven jute fiber reinforced composites with an alkali and coating them with polylactic acid. They discovered that PLA-coated and alkali treated jute fiber reinforced composites exhibited better mechanical characteristics than untreated and uncoated composites. Rana and Gupta [17] investigated the mechanical, thermal and dynamic mechanical properties of hemp nano-cellulose bio-nanocomposites. They reported that adding nano-cellulose to bio-nanocomposites significantly improved their mechanical, thermal, and viscoelastic properties. Kian et al. [18] focused on developing nanocomposites based on PLA because of their high hardness, biodegradability, and sustainability for use in developed products that benefit the environment. Several previous studies have proved the benefit of salinization in improving composite performance. Manufacturers in fields such as aerospace, car, biomedical, and pharmaceutical have begun to transition from synthetic fiber to natural fiber.

From this, we can conclude that the boundaries of natural fibers were determined to be suggestively addressed by a range of surface modification approaches, resulting in improved qualities. The characteristics of natural fibers and their composites can be enhanced by chemical and environmentally friendly treatments. On the other hand, natural fibers and their composites need to be significantly improved for advanced applications. This can be done by applying polymer coatings on naturally treated fibers. The novelty of the present research is to develop eco-friendly jute-banana fiber reinforced hybrid polymer composites with surface modification (NaOH treatment and PLA coating). The effects of PLA coating and alkali treatment on the mechanical attributes and water absorption analysis of jute-banana composite laminates were demonstrated in this study.

Methodology

Materials

The hand lay-up method was used to develop a woven jute-banana fiber reinforced epoxy-based hybrid composites in this work. Jute is derived from the Taxaceae family, whose systematic name is *Corchorus capsularis*, and plant extracts from his *Corchorus* have a lower fiber cost. Jute produces 2300 x 10^3 to 2850 x 10^3 tones worldwide. Jute and banana fibers are widely employed in a variety of industries, including automobile, aerospace, and construction, textiles and packaging sectors. Cut the jute and banana fibers to fit the mold's measurements. In general, thermosetting polymeric epoxy resins feature excellent properties such as better mechanical properties, improved chemical and corrosion resistance, and ease of processing. Epoxy resin was chosen as the matrix material for this study because of its wide potential applications. Curing agents are composed of polyamine monomers. When these materials are mixed, the amine groups [19] react with the epoxide-groups to form covalent bonds. The NH groups can react with epoxide groups, so the resulting polymers are highly cross linked and

very stiff and strong. Hardener additives act as catalysts to accelerate the curing process. Epoxy resin Araridite LY556 and hardener HY951 are used to manufacture composite laminates. Epoxy has the following properties: density = 1.17 g/cm^3, tensile strength = 85 - 95 MPa, tensile modulus = 30 - 33 GPa, and viscosity = 10000 - 13000 MPa.s. The matrix was developed by combining a 10:1 combination of epoxy resin and hardener. Alide Engineering Services provides matrix materials. Vruksha Composites supplied woven jute and banana fibers. Table 1 shows the properties of woven jute and banana fibers.

Table 1: Physical, chemical, and mechanical properties of woven banana jute fiber.

Property	Banana fiber	Jute fiber
Cellulose (%)	63 - 68	58 - 60
Hemicellulose (%)	18 - 20	14 - 20
Lignin (%)	5 - 10	8 - 13
Wax (%)	0.4 - 0.5	0.4 - 0.5
Moisture content (%)	10 - 11	11 - 12
Density (g/cm^3)	1.35	1.3
Tensile strength (MPa)	450 - 530	350 - 470
Young's modulus (GPa)	28 - 35	26 - 30
Elongation at break (%)	1.5 - 1.7	1.5 - 1.8

PLA coating on jute and banana fibers

The PLA pellets were first submerged in a chloroform solution for 8 h. To distribute the PLA in the chloroform solution, the solution was manually agitated and heated at70 °C. After preparing the PLA solvent, weaved jute and banana fibers were soaked for 5 min and then removed [8]. Finally, the coated fibers were dried out in a hot air oven at ambient temperature for 24 h, followed by 4 h at 60 °C. Table 2 shows the properties of PLA material. Jute fiber before and after surface treatment, as illustrated in figure 1. A schematic process of PLA coating on jute and banana fibers as shown in figure 2.

Table 2: Physical and mechanical properties of PLA.

Properties	Range
Structure	Semi crystalline
Tensile strength (MPa)	37
Tensile modulus (GPa)	2.7 - 16
Density (g/cm^3)	1.28
Melting temperature (°C)	173 - 178
Elongation at break (%)	20 - 30

Figure 1: Jute fiber before surface modification and after surface modification.

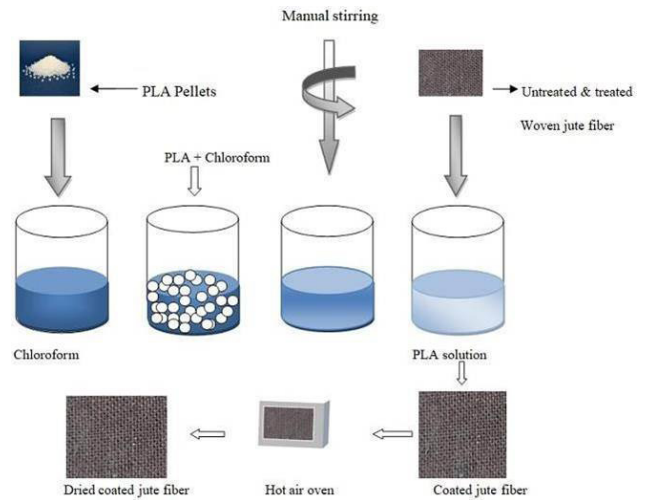

Figure 2: PLA coating on untreated and treated fiber.

Alkaline treatment on jute and banana fiber

The current investigation uses woven jute and banana fibers that have been treated with 2% NaOH. For four hours, jute and banana fibers were submerged in an alkali solution at 30 °C. After that, the fiber was taken from the solution, washed frequently under running water, and submerged in a hydro chloride solution to eliminate NaOH deposits from the fiber's outer [16]. The fibers were rinsed again with normal water and dried for 24 h in a 60 °C hot air oven.

Fabrication of composite laminates

Hardened steel rectangular molds are used for manufacturing laminates of the specified dimensions. The mold used to make the laminate is 300 mm x 300 mm and 4 mm thick. Due to the flexibility of material design and availability, hand lay-up method is used in this work to fabricate composite laminates. Measure the layers of jute and banana fiber and cut according to the mold specifications. The amount of resin is calculated based on the fabric's GSM. Add 10:1% by weight of low temperature curing epoxy resin LY-556 and curing agent HY-951 to the adhesive and thoroughly mix with a mechanical stirrer. The weight of jute and banana remains constant at 40%. Table 3 shows composite laminates of untreated, coated, treated, and treated and coated various compositions marked JB1, JB2, JB3, and JB4, respectively. Finally, the laminate is sliced using a hacksaw to acquire specimens for characterization and testing in accordance with ASTM standards. Figure 3 depicts a schematic of the production process.

Table 3: Nomenclature of composites.

Composite's	Fiber (wt.%)	Alkaline treatment (wt.%)	PLA coating (wt.%)
JB1	40	-	-
JB2	40	-	2
JB3	40	2	-
JB4	40	2	2

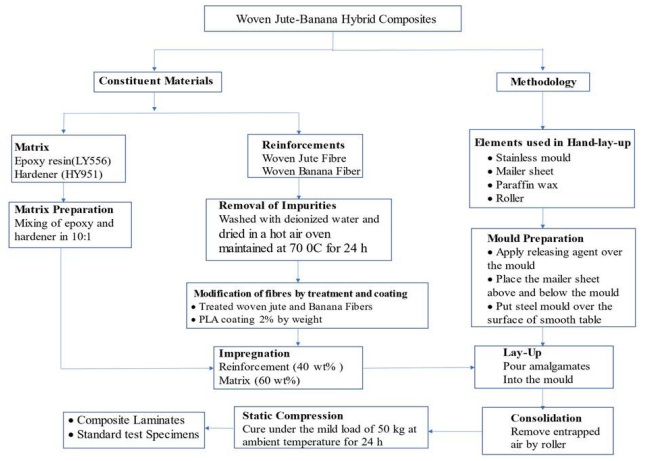

Figure 3: Fabrication process of the composite laminates.

Results and Discussion

The epoxy resin LY-556 and hardener HY-951 are employed in this study to developed the hybrid composite laminates reinforced with surface modified jute and banana fibers. To analyze the mechanical characteristics such as tensile, flexural and impact also evaluated the percentage of water absorption.

Analysis of tensile strength

Tensile tests are performed on prepared hybrid composite samples in accordance with the ASTM D-3039 standard on rectangular sample sizes of 250 x 25 x 3 mm. Tensile tests are carried out on five samples of each laminate: untreated, PLA-coated, NaOH-treated, and PLA-coated and NaOH-treated. The samples were loaded to failure during testing. The stress vs strain curve is used to calculate the tensile strength.

The experimental tensile strength values for the jute/banana fiber reinforced hybrid composites with NaOH treated and PLA coated, NaOH treated, untreated, and PLA coated are displayed in figure 4. The favorable impacts of eco-friendly treatment (NaOH treatment) and bio-coating (PLA coating) of jute/banana fibers on composite tensile strength were observed. The untreated jute/banana fiber-reinforced hybrid composite has a lower tensile strength than the PLA coated composite and NaOH treated composite. The tensile strength of developed composites PLA-coated hybrid sample (JB2), NaOH-treated hybrid sample (JB3), and NaOH-treated and PLA-coated hybrid composite sample (JB4) improved, when compared to an untreated mixed composite material sample (JB1), the tensile strength was 3.06%, 8.23%, and 20.56%. The jute/banana fiber-reinforced composite specimen treated with NaOH and coated with PLA (JB4) has the maximum tensile characteristics, which can be due to the blended effect of alkali treatment and PLA coating on the fibers surface. The tensile properties of the present composites were found to be close to those reported in previous studies [16]. The PLA coating and NaOH treatment of jute/banana fiber increases the hydrophobic characteristics of the fiber as much as feasible, allowing for a strong bonding of the surface to the matrix.

Analysis of flexural strength

Flexural tests were performed on the developed composite laminates using a universal testing machine (Intron 1195) in accordance with ASTM D-790. Bending tests on specimens (125 mm x 13 mm x 3 mm) were performed at a crosshead speed of 1 mm/min. We presented the average including the standard deviation for flexural strength after evaluating the five samples of each composite.

The untreated jute/banana fiber reinforced hybrid composite sample (JB1) exhibits low flexural strength due to inadequate surface wetting and fiber-resin bonding, as shown in figure 5. The flexural strength of the PLA-coated jute/banana hybrid composite sample (JB2) is 5.2% greater than that of the untreated hybrid composite sample (JB1). The NaOH-treated jute/banana fiber reinforced hybrid composite sample (JB3) has a 7.5% higher flexural strength improvement than the untreated composite sample (JB1). The NaOH-treated and PLA-coated jute/banana fiber reinforced hybrid composite sample (JB4) had the highest flexural strength value. The NaOH-treated and PLA-coated jute/banana fiber reinforced hybrid composite structure has a flexural strength of 88.5 MPa. Because of the increased interfacial contact between fiber and matrix, the NaOH-treated and PLA-coated hybrid composite structure (JB4) has a 16.7% higher flexural strength than the untreated hybrid composite structure (JB1).

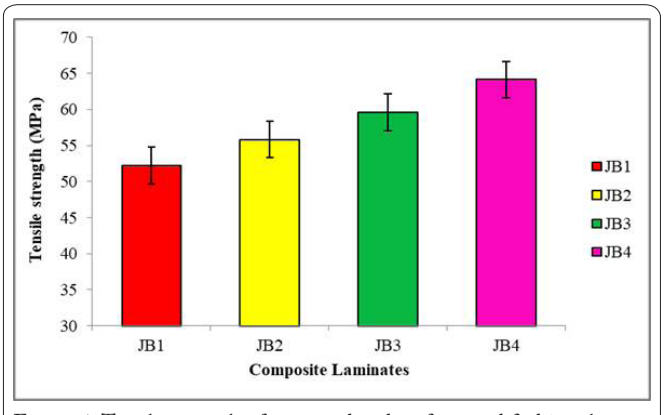

Figure 4: Tensile strength of untreated and surface modified jute-banana hybrid composites.

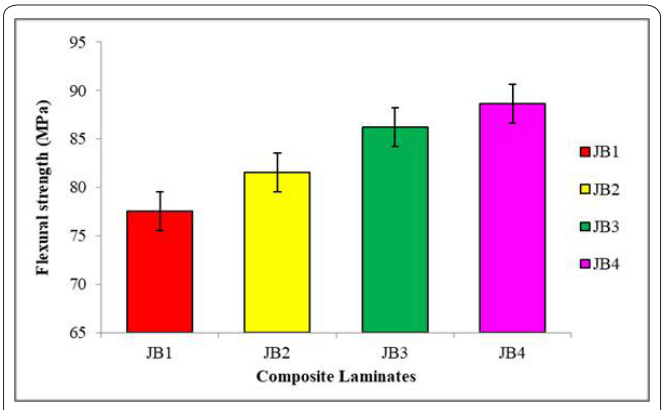

Figure 5: Flexural strength of untreated and surface modified jute-banana hybrid composites.

Impact strength analysis

An Izod impact test was performed on prepared hybrid composite samples in accord with the ASTM D-256 exploiting a digital impact tester (Presto Izod/Charpy impact tester). Samples with dimensions of 65 x 13 x 3 mm were prepared for this test. Average impact energy values were provided after testing five samples of each composite laminate.

Composite impact strength is primarily determined by interfacial strength and fiber elongation length. The trends in the impact test findings are seen to be opposed to the trends in the tensile and flex test results. Figure 6 shows that the impact energy of the PLA coated and alkali treated composite (JB4) is 20.63% lower than the impact energy of the untreated composite (JB1). Composite JB4 decreased impact strength could be attributed to the removal of non-cellulosic components from the fiber surface that improves bonding with the resin. The NaOH treatment and PLA coating improves the bonding between fibers and matrix, resulting in less fiber pull-out and impact resistance. Because aspect ratio influences impact strength, composites with high fiber aspect ratios absorb less impact energy and vice versa [3]. Because of the low aspect ratio fiber reinforcement, the JB1 composite has the highest impact energy.

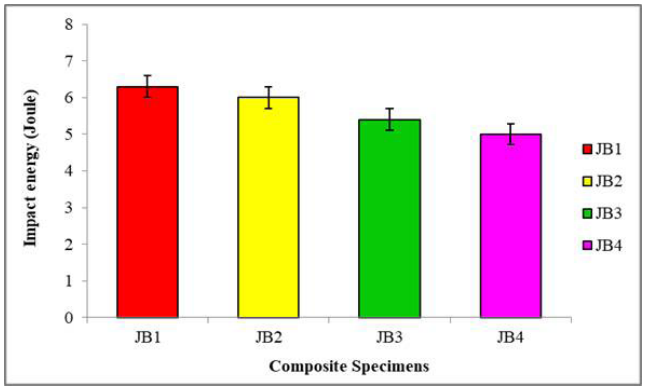

Figure 6: Impact energy of untreated and surface modified jute-banana hybrid composites.

Water absorption analysis

The water absorption test is used to determine the amount of moisture that a composite laminate absorbs. The ASTM D-570 standard is used to prepare water absorption specimens. Prior to testing, samples are equally dried and weighed by using precision electronic balance. The weight difference between the dry sample (W1) and the wet sample (W2) is then used to compute moisture absorption. The water uptake of composite samples was calculated using the equation below. The percentage of water absorbed by all composite specimens' increases at certain time intervals of 15, 30, 45, 60, 75, and 90 days. The water absorption percentage was calculated by using equation 1.

$$\text{Water absorption } (\%) = \left| \frac{W_1 - W_2}{W_2} \right| \text{ x } 100 \qquad (1)$$

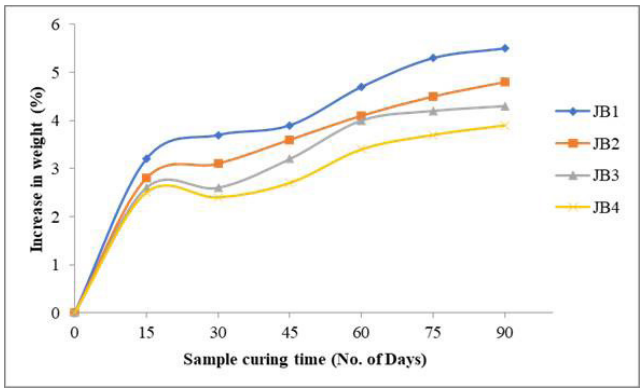

Figure 7: Variation of sample weight (%) against sample curing time (No. of days).

According to figure 7 the initial water absorption rate is greater for the first sixty days before reaching saturation and absorbing no more water. Because of the hydrophilic nature of the fibers and the highest cellulose content, the composite laminate (JB1) has the greatest water absorption. The composite laminate (JB4) had the least amount of water absorption (3.9%). As a result of removing lignin and hemicelluloses, the NaOH treatment enhances fiber-to-matrix adhesion. The PLA coating prevents water absorption by acting as a protective barrier.

Conclusions

This work has successfully analyzed mechanical characteristics and water absorption behavior with effect of NaOH treatment and PLA coating on jute-banana hybrid composite laminates. Followed by hand lay-up manufacturing to develop the hybrid composite plates. The following are the specific conclusions of the investigation.

- Individual properties of jute and banana fibers affect the tensile strength of hybrid composite samples. Improved tensile and flexural strength of the PLA coated and NaOH treated jute/banana fiber reinforced hybrid composite sample (JB4) are observed. PLA coating and NaOH treatment reduce impact energy.
- The tensile and flexural strengths of the PLA-coated and alkali treated jute-banana fiber-reinforced hybrid sample (JB4) are enhanced by 20.56% and 16.77%, respectively, when compared to the untreated hybrid composite structure (JB1).
- The impact energy and water absorption of the PLA-coated and NaOH-treated jute/banana fiber reinforced hybrid composite sample (JB4) are 20.63% and 47.6% lower, respectively, when compared to the untreated hybrid composite structure (JB1).

Acknowledgements

None.

Conflict of Interest

None.

References

1. Madhu P, Rangappa SM, Khan A, Al Otaibi A, Al-Zahrani SA, et al. 2020. Experimental investigation on the mechanical and morphological behavior of *Prosopis juliflora* bark fibers/E-glass/carbon fabrics reinforced hybrid polymeric composites for structural applications. *Polym Compos* 41(12): 4983-4993. https://doi.org/10.1002/pc.25768
2. Suresh A, Jayakumar L, Devaraju A. 2021. Investigation of mechanical and wear characteristic of banana/jute fiber composite. *Mater Today Proc* 39: 324-330. https://doi.org/10.1016/j.matpr.2020.07.426
3. Sahu P, Gupta MK. 2019. Effect of ecofriendly coating and treatment on mechanical, thermal and morphological properties of sisal fibre. *Indian J Fibre Text Res* 44(2): 199-204.
4. Sahu P, Gupta MK. 2019. Enhancement in erosion wear resistance of sisal composites by eco-friendly treatment and coating. *Mater Res Express* 6(8): 085348. https://doi.org/10.1088/2053-1591/ab29b5
5. Gupta MK, Srivastava RK. 2016. Mechanical properties of hybrid fibers-reinforced polymer composite: a review. *Polym Plast Technol Eng* 55(6): 626-642. https://doi.org/10.1080/03602559.2015.1098694
6. Fiore V, Scalici T, Nicoletti F, Vitale G, Prestipino M, et al. 2016. A new eco-friendly chemical treatment of natural fibres: Effect of sodium bicarbonate on properties of sisal fibre and its epoxy composites. *Compos Part B Eng* 85: 150-160. https://doi.org/10.1016/j.compositesb.2015.09.028
7. Gupta MK, Singh R. 2019. PLA-coated sisal fibre-reinforced polyester composite: water absorption, static and dynamic mechanical properties. *J Compos Mater* 53(1): 65-72. https://doi.org/10.1177/0021998318780227
8. Yadav A, Gupta MK. 2019. Development and characterization of jute composites for sustainable product: effect of chemical treatments and polymer coating. *Mater Res Express* 7(1): 015306. https://doi.org/10.1088/2053-1591/ab5bd9
9. Sahu P, Gupta MK. 2020. Lowering in water absorption capacity and mechanical degradation of sisal/epoxy composite by sodium bicarbonate treatment and PLA coating. *Polym Compos* 41(2): 668-681. https://doi.org/10.1002/pc.25397
10. Gunti R, Prasad AVR, Gupta AVSSKS. 2018. Mechanical and degradation properties of natural fiber-reinforced PLA composites: jute, sisal, and elephant grass. *Polym Compos* 39(4): 1125-1136. https://doi.org/10.1002/pc.24041
11. Ismail AS, Jawaid M, Naveen J. 2019. Void content, tensile, vibration and acoustic properties of kenaf/bamboo fiber reinforced epoxy hybrid composites. *Materials* 12(13): 2094. https://doi.org/10.3390/ma12132094
12. Trivedi AK, Gupta MK, Singh H. 2023. PLA based biocomposites for sustainable products: a review. *Adv Ind Eng Polym Res* 6(4): 382-395. https://doi.org/10.1016/j.aiepr.2023.02.002
13. Rangappa SM, Parameswaranpillai J, Siengchin S, Thomas S. 2022. Handbook of Epoxy/Fiber Composites. Springer Nature.
14. Kumar KS, Siva I, Jeyaraj P, Jappes JW, Amico SC, et al. 2014. Synergy of fiber length and content on free vibration and damping behavior of natural fiber reinforced polyester composite beams. *Mater Des* 56: 379-386. https://doi.org/10.1016/j.matdes.2013.11.039
15. Venkataravanappa RY, Lakshmikanthan A, Kapilan N, Chandrashekarappa MPG, Der O, et al. 2023. Physico-mechanical property evaluation and morphology study of moisture-treated hemp–banana natural-fiber-reinforced green composites. *J Compos Sci* 7(7): 266. https://doi.org/10.3390/jcs7070266
16. Sagar PN, Reddy CHN, Malyadri T. 2022. Enhancement of Mechanical Properties Alkali-Treatment and Polylactic Acid Coated Woven Jute Fiber Reinforced Composites. In Dave HK, Dixit US, Nedelcu D (eds) Recent Advances in Manufacturing Processes and Systems. Lecture Notes in Mechanical Engineering. Springer, Singapore, pp 403-413.
17. Rana SS, Gupta MK. 2021. Fabrication of bionanocomposites reinforced with hemp nanocellulose and evaluation of their mechanical, thermal and dynamic mechanical properties. *Proc Inst Mech Eng Part L J Mater Des Appl* 235(11): 2470-2481. https://doi.org/10.1177/14644207211004640
18. Kian LK, Saba N, Jawaid M, Sultan MTH. 2019. A review on processing techniques of bast fibers nanocellulose and its polylactic acid (PLA) nanocomposites. *Int J Biol Macromol* 121: 1314-1328. https://doi.org/10.1016/j.ijbiomac.2018.09.040
19. Reddy CHN, Kumar JS, Bhargav M. 2019. Mechanical and physical properties of epoxy based unidirectional banana/glass fiber reinforced hybrid composites. *AIP Conf Proc* 2057(1): 020024. https://doi.org/10.1063/1.5085595