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Synthesis and Characterization of Jute and Banana Fiber Reinforced Polyester Composites

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Abstract

The superior inherent properties like low density, lower consumption of energy and low cost, when compared with synthetic fibers, some of the widely used natural fibers utilized for manufacturing composites include banana, hemp, jute, sisal, coir, and bamboo fibers. Apart from the mentioned advantages, unlike man-made fibers, natural fibers are biodegradable, abundantly available, renewable, and hence they are widely adopted for use. Current work focusses on preparing the polyester hybrid composites reinforced with banana and jute fibers. Composites were manufactured by compression molding technique; both the fibers were chemically modified using sodium hydroxide (NaOH) and potassium hydroxide (KOH) for 5% of solution concentrations about 48 hours before fabrication. Composites are investigated for impact, flexural, tensile and compression behaviors and the tests were carried out as per ASTM standards. Thermogravimetric analysis (TGA) is also carried out on the hybrid composites to evaluate their thermal properties. The influence of chemical treatments on the surface of reinforcements is evident by mechanical and physical characterization. In part of this, the fractography analysis is comprehensively examined by optical microscope as well as Scanning Electron Microscope (SEM) to determine the influence of chemical modification on composites. Finally, it is observed that jute and banana fiber hybridization can be a potential reinforcement for making low load-bearing fiber-reinforced polymer composite products.

Keywords

Jute fibre, Banana fibre, Hybrid composite, Polyester, Sodium hydroxide, Potassium hydroxide

Introduction

Selection of material is an important process to enhance the employability of product for diverse applications. In this point of view manmade fibers like Kevlar, glass, carbon, and aramid fibers are dominating in all versatile aspects. The major drawbacks of synthetic fibers are high cost, maximized processing technique, not being eco-friendly, and being human hazardous. Bio-fibers such as flax, ramie, kenaf, snake grass, vetiver, areca, bamboo, pineapple, abaca, sisal, and jute are renewable resources as well as even agricultural waste of these natural fibers are used to make composites. The selection of natural fiber for making composite takes into consideration such as density, length/diameter ratio, thermal conductivity, cellulose and lignin content, availability of natural fiber, cost of the fiber and other mechanical properties [1]. In this concern, the polymer matrix composites reinforced with natural fibers are having the potential to compete with man-made fiber. The feasibility of utilizing fiber of date palm for industrial applications was carried out and was proven to be superior when compared with other natural fibers [2]. The selection of natural fibers is mainly based on the availability, compatibility, and sustainability in all aspects of applications where an elaborate study was to identify the most suitable natural fiber for automotive study, the result shows the flax and palm natural fibers were found to be potentially one among others [3 - 4]. The strength and reliability of fiber composite products are mainly based on the presence of fiber inside the composites, a comprehensive study was done to analyse the porosity and volumetric interaction of plant fiber inside the composites [5]. In part of mechanical behavior, the natural fiber composites do not exhibit better properties than synthetic fibers. To compete with synthetic fiber the processing of natural fiber like rope, foams, and woven mat were shown improved mechanical properties [6]. When compared to hybrid composites, thermosetting composites based on natural fibers often have lesser strength. Natural fibers with petroleum/synthetic based fibers leads to enhancement of impact and moisture absorption properties of the composites. The alkali treatment of natural fiber incorporated with synthetic fiber reinforced with polyester matrix improves the thermal resistance property. The hybridization effect makes these types of natural/synthetic composites have better impact property and it can be more suitable for developing better impact materials for transportation and constructional applications [7]. In addition to this the manufacturing process of fiber composites also plays a vital role, the compression moulded kenaf/polypropylene composite exhibits superior mechanical properties [8]. However, the replacement of synthetic fiber using natural fiber mainly subjected to greater availability of such fibers, the novel sansevieria cylindrical fiber were characterized to calculate physical, chemical, mechanical, and micro structural properties [9]. A significant study was made for kenaf fiber with varieties of polymers to identify improved mechanical and physical properties [10, 11]. The properties of fiber-reinforced composites mainly depend on the binding ability between fiber and matrix, the fibers chemical composition, hydrophobicity and hydrophilic are all the important parameters to influence the binding ability of fiber. Generally, natural fibers are hydrophilic by nature which highly influences the mechanical properties of the composites. The surface modification of chemical treatment is a promising technique that renders the fibers which will be hydrophobic towards the water. A prominent review was conducted by many researchers on the variety and suitability of chemical agents that could be applied on numerous natural fibers [12 - 14]. An appreciable improvement in flexural strength of KOH treated areca fibers are found out from a study, when compared with the untreated fibers. It is concluded that the improved mechanical and physical behavior were attained by adopting the surface treatment of NaOH treatment for areca fiber [15 - 21]. In general, fibers are load-carrying members inside the composites, fiber parameters such as its diameter, length, chemical composition, and surface treatment are finalizing the properties of composites. Apart from this, hybridization of fiber reinforcement shows better physical and mechanical behaviors, the hybrid glass/jute/epoxy composites exhibit improved mechanical properties based on the hybrid reinforcements [22]. The hybrid kenaf/banana composites flexural and impact strength are superior after the surface treatments, also woven fabric hybrid composite gives enhanced mechanical properties [23]. In general, the natural fiber hybrid composites are providing enhanced properties only by adding one synthetic fiber inside the composites such as glass and Kevlar fibers [24 - 26]. Meon et al. [27] studied the efforts to enhance the tensile strength of the kenaf fibers by treating the fiber with NaOH. At the end of their study, it has been found that the treated natural Kenaf fiber at an optimum of 6% NaOH shows better tensile strength when compared with the untreated fiber. Vilay et al. [28] studied the mercerization and acrylic acid chemical treatments of Bagasse fiber. The treated fiber composites had better tensile and flexural properties and the water intake was reduced compared with untreated fiber composite. Narendar and Dasan [29] analysed the influence of various alkali pre-treatments of coir pith and compared the chemical compositions of treated and untreated. Chemical treatment proves the surface modification of the coir pith through morphology analysis. Kim et al. [30] investigated the surface modification of bamboo fiber with NaOH solution. The treated bamboo fiber shows better tensile properties than raw fibers. Hemicellulose and lignin are removed effectively due to the NaOH treatment. Edeerozey et al. [31] analysed the morphological characteristics and structural changes of the alkaline treated and untreated kenaf fibers. Based on SEM analyses, they found fewer impurities in treated (6% NaOH) fibers than the untreated fibers. The surface morphology provides a very important inference about compatibility between hydrophilic fiber and hydrophobic matrix, fiber breakage, and fiber pull-out. Sharma et al. [32] studied the mechanical properties of citrus limetta peel filler reinforced epoxy composites as a function of the weight fraction of filler. They have concluded that tensile, flexural and impact strength of composites were decreased when an increase of *Citrus limetta* peel filler in epoxy resin due to poor interfacial adhesion between fillers and epoxy resin. Singh et al. [33] investigated the tensile and flexural properties of jute fibers reinforced Polylactic Acid (PLA) composites as a function of fiber volume fraction. The increase in fiber volume fraction to 30% at 160 °C curing temperature increased tensile and impact strength of composites owing to the homogeneous dispersion of jute fibers in the PLA matrix. Kumaran et al. [34] evaluated the effect of incorporation of *Portunus sanguinolentus* shell powder in jute fibers reinforced epoxy composites. They have concluded that tensile, flexural, impact strength and hardness of composites are improved when increase of *P. sanguinolentus* shell powder in epoxy resin to 10% by weight due to better interaction between fillers and fibers with epoxy resin. Based on the various literatures survey, the present study is attempted to develop jute and banana fiber reinforced hybrid polymer matrix composites. The effect of NaOH and KOH on the mechanical and thermal properties of jute and banana fibers reinforced polyester hybrid composites was investigated. Along with the effect of weight fraction of jute and banana fibers on the mechanical and thermal properties of the hybrid composites studied. The mechanical and thermal behavior of composites are analysed experimentally to substantiate the governance of the process of surface modification of fibers over the composite properties.

Materials and Methods

The composite comprises hybrid reinforcements of banana and jute fibers along with also polyester resin as a matrix phase, the jute and banana reinforcements are abundantly available in the local region of India. The well-extracted banana and jute fibers were purchased in the local market from Coimbatore, Tamil Nadu, India. The chemical and physical composition of banana and jute fibers listed in table 1. The unsaturated polyester resin and its hardeners was purchased from Seenu & co, Coimbatore, Tamil Nadu, India. Figure 1 depicts the jute, banana, and polyester resins.

Chemical treatments

Notable micro-level constituents present in the natural fibers include pectin, lignin, hemi cellulose, cellulose, and ash, out of which pectin and ash play a pivotal role in reducing the ability of fibers to bind with the matrix [35]. A variety of chemical treatments are available to remove unwanted contaminations from natural fiber surface, in this regard the chemical processing of alkaline treatment plays a vital role [36 - 38]. The current study focuses on the evaluation of the impact on various chemical modification processes upon the fiber surface, the chemical treatment of NaOH and KOH treatments have been performed for this investigation. Figure 2 depicts the arrangement of chemical treatments, for both treatments the fibers are treated individually by the solution concentration of 5% for 48 hours. Chemically modified fiber morphology is analysed under an optical microscope (100x to 1000x, Metzer, India) for examining the impact of chemical treatment on natural fibers. Figure 3 shows the fiber surfaces after chemical treatments.

Fabrication process

The processing methods of composites are also one of the important parameters, in this study the compression moulding technique is being adopted to fabricate hybrid reinforced polymer composites. In general, the compression moulding technique contains many advantages like proper distribution of matrix materials, avoiding air holes, achieving required dimensions and arrangement of fibers. The 300 mm x 300 mm x 5 mm plates are fabricated using a compression moulding machine (Hydraulic, Modern Plastics, India) for different concentrations of hybrid reinforcements. The compression moulding machine offers temperature-controlled zone to cure the polyester resin in a proper way to improve binding ability between fiber and matrix. Five samples were prepared in the same order using different fiber content. Then the completed laminates were placed inside the modern compression molding machine and maintained at a temperature and pressure of 120 °C and 35 bar for 45 minutes and the laminates were cured for another 45 minutes. Figure 4 shows the fabrication sequences of hybrid composites.

Table 1: Physical and chemical composition of banana and jute fiber.

Properties	Banana Fiber	Jute Fiber
Cellulose (%)	61 - 65	59
Hemicellulose (%)	18	15
Lignin (%)	5.1	9.5
Density (kg/m^3)	1356	1298
Tensile strength of fiber (MPa)	547 - 921	420 - 730
Youngs modulus (GPa)	34.6	26.8
Diameter (µm)	81 - 256	120 - 180

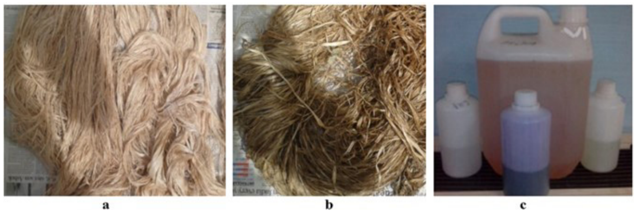

Figure 1: (a) Raw banana fiber, **(b)** Raw jute fiber, and **(c)** Polyester and Hardener.

Figure 2: Banana fibers and jute fibers are immersed in KOH.

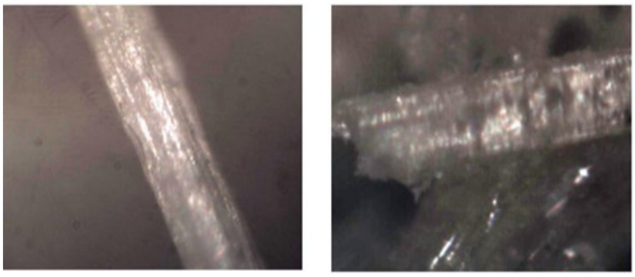

Figure 3: Microscopic analysis of **(a)** Banana fibers and **(b)** Jute fibers.

Evaluation of mechanical Properties

Hybrid composites prepared through compression moulding technique has been cut out as per ASTM standard to carry out tensile, flexural, compression and impact test. Standard of tests was followed: for tensile, flexural, impact and compression tests ASTM D638, ASTM D790, ASTM D256 and ASTM 695, respectively. Properties are analysed experimentally using a universal testing machine (UTM 50 kN, Instron, India) for tensile, flexural and compression behaviors and Tinius Olsen Izod impact tester (Low velocity, Shanta, India) for impact behavior. Averages of five values are considered while testing the specimens in each composition. Similarly, the compression testing was also carried out for all composite specimens to analyse the ability to sustain compression load. Finally, the fractography analysis has been carried out for all fractured specimens to characterize the influence of chemical treatments on reinforcements. Table 2 present the formulation of hybrid composites.

Thermogravimetric Analysis (TGA)

TGA is an important experimental analysis to evaluate the thermal stability of composites. The un-treated and chemically

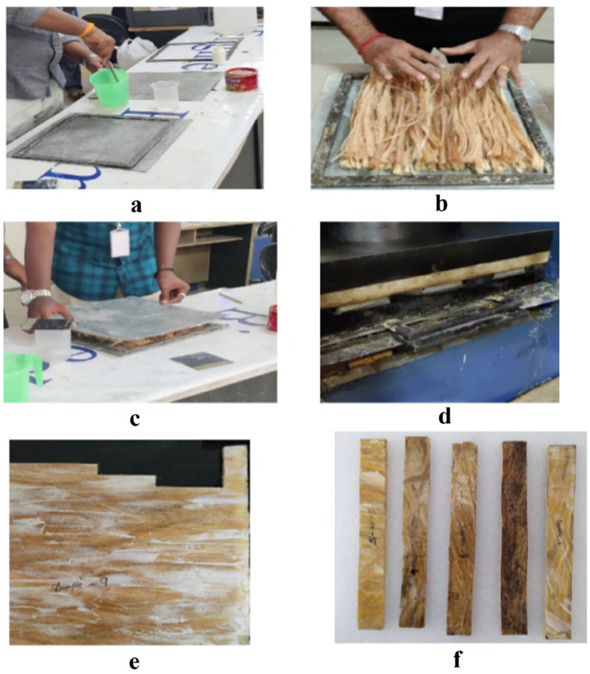

Figure 4: Graphical flowchart of fabrication sequence **(a)** Mould preparation, **(b)** Fiber arrangements, **(c)** Fiber stacking, **(d)** Fiber stacking under temperature and amp pressure **(e)**, Final composite laminate **(f)** tensile samples as per ASTM Standards.

Table 2: Formulation of composites.

Sample Code	Reinforcement Matrix (wt.%)		
	Banana	Jute	Polyester
S1	0	25	75
S2	5	20	75
S3	10	15	75
S4	15	10	75
S5	20	5	75
S6	25	0	75

treated fibers have been characterized by the TGA (RT to 1100 °C, Mettler, India) technique, initially the un-treated and chemically treated fibers were ground to obtain particles, and then the particles were kept in temperature-controlled zone. The temperature-controlled chamber always indicates the temperature differences and weight loss of composite particles.

SEM and optical microscope

The morphology analysis of fiber and composites were exposed by SEM (JSM799F, JEOLs, Japan) as well as the optical microscope. There are two micrograph analyses are carried for treated and untreated fibers and fractography analysis for mechanically tested composites. The validations of micrographs are comprehensively examined by number of the microscope pictures.

Results and Discussion

Effect of fiber surface treatment

This segment mainly focuses to study the influence of two different fiber treatments (NaOH and KOH) on fiber surfaces. The collected banana and jute fibers were treated by NaOH and KOH chemicals with 5% solution concentration about 48 hours for preliminary studies. Initially the natural fibers have been cleansed using running distilled water and dried in room temperature for chemical treatment. In part of NaOH treatment the fibers were treated with 5% solution concentration about 48 hours, similarly the same condition was performed for KOH treatment. The treated fibers are again cleaned and dried to remove the continuous effect of chemicals on fibers. The morphological analysis after the chemical treatment is done by optical microscope; the influence of chemical treatment on fiber surface was analysed graphically.

In general, the chemical treatments are intended to remove unwanted wax and other contaminations on fiber surfaces, but in reality, the chemical treatments are also removed all the required chemical compositions such cellulose, hemi-cellulose, lignin, and pectin. This could be enough for better bonding purpose between the fiber and matrix. On the whole, this chemical treatment aimed to convert the hydrophilic nature of fiber surfaces into hydrophobic nature for improving binding ability. The microscope images are graphically exposed the fiber surfaces before and after chemical treatments in figure 5. As discussed earlier the treated fiber surfaces are highly influenced by chemicals and fiber surfaces become rough (amorphous nature) intentionally to improve binding ability.

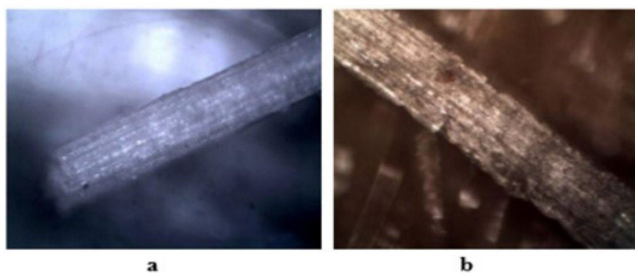

Figure 5: Microscope images after chemical treatment **(a)** banana fiber and **(b)** jute fiber.

Effect of treated hybrid reinforcement in mechanical properties of composites

The polyester matrix was reinforced with the chemically treated banana and jute fibers and the mechanical tests such as tensile, flexural, compression and impact were done to find their ability. The composites were fabricated with different concentrations of hybrid fiber, a total of 18 composite specimens were fabricated by compression moulding machine, from these 6 specimens have been untreated, 6 specimens NaOH treated, and 6 specimens KOH treated fibers. Figure 6, figure 7, figure 8, figure 9, and figure 10 shows the tensile, flexural, compression, impact, and hardness properties of untreated, NaOH and KOH treated fibers, respectively. Comparing the values from figure 6 to 10 the mechanical properties were differing for various concentrations of hybrid reinforcements. It shows the differences of mechanical properties of by various peaks, the tensile and flexural properties have been increased about the fiber concentration of 25% (sample S3 10% banana and 15% jute). As similar to this, the compression, impact and hardness properties have been increased at same fiber concentration of 25% (sample S25% of banana and 20% jute).

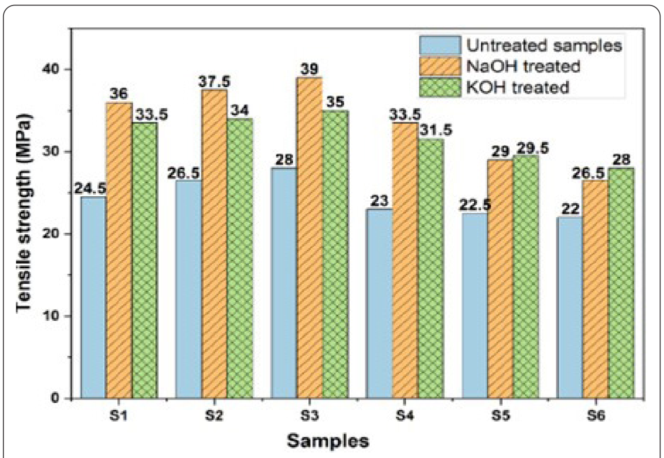

Figure 6: Tensile strength of untreated, NaOH, and KOH treated composites.

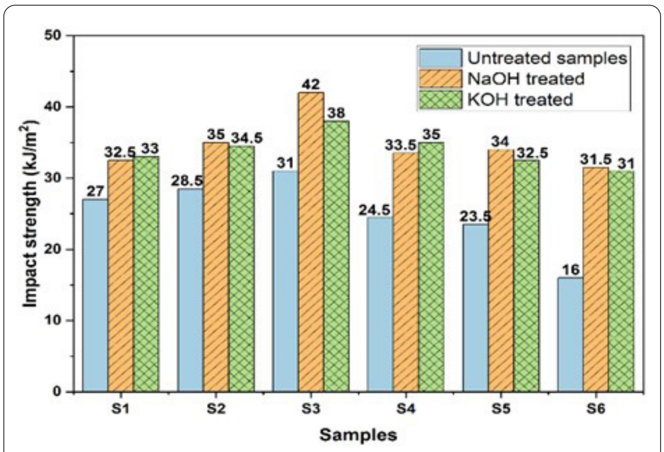

Figure 9: Impact strength of untreated, NaOH, and KOH treated composites.

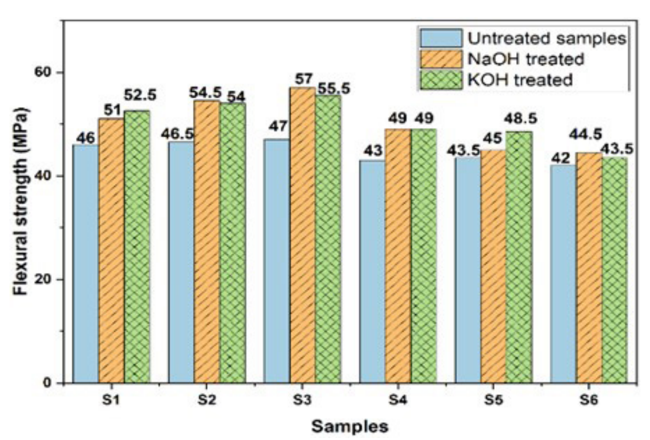

Figure 7: Flexural strength of untreated, NaOH, and KOH treated composites.

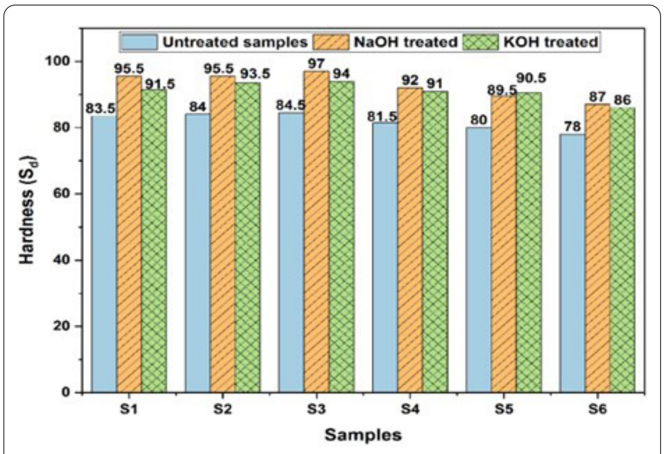

Figure 10: Hardness values of untreated, NaOH, and KOH treated composites.

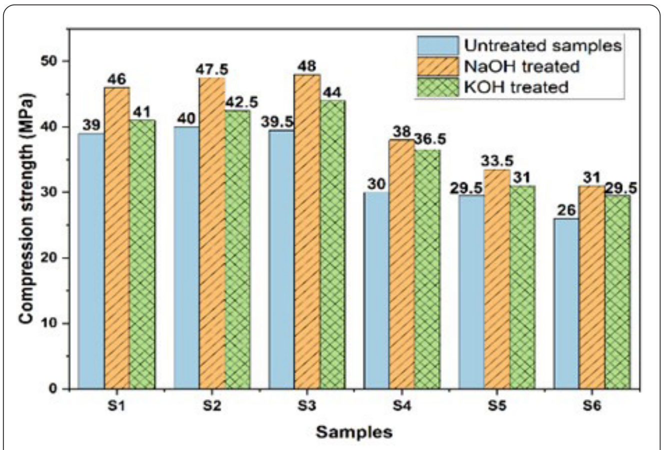

Figure 8: Compression strength of untreated, NaOH, and KOH treated composites.

Effect of temperature difference on composites

Thermal stability of natural fibers and composites are most important factor want to be considered for the employability of composites in all aspects of applications. The fibers (banana and jute) are kept at temperature-controlled atmosphere to analysis the performance for various temperature ranges. The fine-grained fibers weight percentages between 4 mg (2 mg banana and 2 mg jute fibers) have been placed thermal analysis instruments and heated from 30 °C to 800 °C with the temperature range of 10 °C per minute. The figure 11 expressed the reaction of fibers for various temperature ranges, from this study may it conclude the fibers could sustain up to 550 °C and above 550 °C the fibers became ash at last. The chemical composition of fibers was burned in different stages of temperatures.

Thermal analysis is carried out for hybrid fibers, from this analysis the hybrid fiber exhibits better thermal stability. The first degradation of fiber was takes at 320 °C shown by first peak shoulder, where the thermal depolymerisation of hemi cellulose and pectin content was takes place. It is observed that the second peak is takes place at 400 °C by decomposing cellulose content. At last, the whole degradation of fiber has been observed at 550 °C by decomposing lignin content.

Morphology analysis by SEM and optical microscope

The figure 12a presents the fiber pull out and fiber break from the matrix while tensile testing, also the figure 12b shows the hybrid-fiber and matrix interaction. The SEM images have been taken from vacuum atmosphere to capture fractured surfaces; the fracture surfaces of the specimens were investigated using a SEM. Figure 12a shows the fiber pull out from the matrix as similar to this figure 12b depicts the fiber break while tensile testing. From this SEM images, it is observed that the

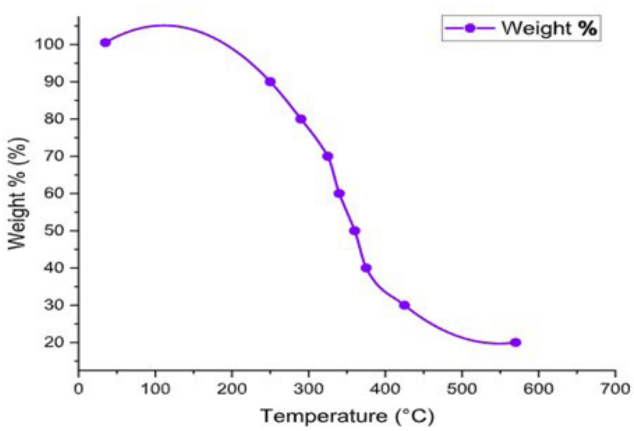

Figure 11: TGA of treated fiber composites.

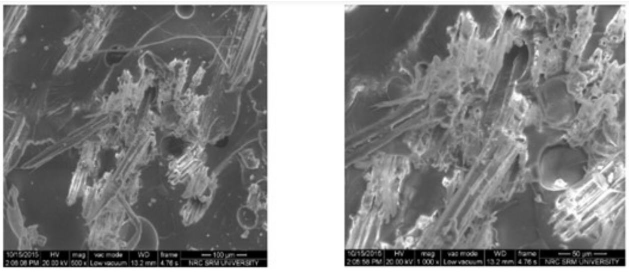

Figure 12: SEM Micrograph of **(a)** untreated fibers and **(b)** NaOH treated fibers.

treated fibers are having good mechanical interlocking with matrix comparatively untreated fibers. The surface morphology analysis of chemically treated and un-treated fibers is carried out using optical microscope. The trinocular metallurgical microscope (100x to 1000x) integrated with computer was used to study the fiber surface, the microscope study has been segmented in to two as first phase deals the fiber chemical treatment, and second phase deals the binding ability between fiber and matrix.

It is concluded from microscope image that the chemically treated fibers have been not pulled-out from matrix rather than treated fiber were got broken while applied load for different mechanical characterization, due to the chemical treatment on fiber surface, the binding ability between fiber and matrix was improved up to the level.

Conclusion

Mechanical and thermal behavior of chemically treated hybrid fiber-reinforced polymer composites have been evaluated experimentally. The fiber surface modification is done by using NaOH and KOH chemical solution; the banana and jute hybrid fibers were properly reacting for chemical treatments in terms of mechanical properties. Variation of mechanical properties between untreated fibers and treated fiber composites was noteworthy and the treated fiber composites have been observed to behave better. NaOH treated hybrid fiber-reinforced composite expressed better mechanical property than KOH treated fibers. From this comparative study it is observed that the alkaline treatment (NaOH) was economic as comparatively KOH treatment, though the KOH treated hybrid fiber-reinforced composite shows better property than un-treated hybrid composites. In part of the reinforcement phase straight away the jute fiber reinforcement plays a vital role in all sorts of mechanical properties as compared with the weight percentage of banana reinforcement. Thermal analysis of the natural fiber composites revealed that the decomposition of composite is very slow with an increase of jute fiber volume concentrations.

- The jute and banana hybrid fiber-reinforced composite show better mechanical and physical properties than jute fiber-reinforced composite and banana fiber-reinforced composite. It is concluded that the hybridization of jute and banana fiber exposes good agreement between them for hybrid composite.
- There are two chemical surface modification processes carried out for both jute and banana fibers namely NaOH and KOH treatments. As comparatively un-treated hybrid composites over the treated fiber composite exhibit better properties in all aspects.
- The effective employability of fiber composite products based on thermal stability; in this work the improved thermal stability was attained for hybrid fibers.

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Conflict of Interest

None.

References

1. Sathish S, Prabhu L, Gokulkumar S, Karthi N, Balaji D, et al. 2021. Extraction, treatment and applications of natural fibers for bio-composites–a critical review. Int Polym Process 36(2): 114-130. https://doi.org/10.1515/ipp-2020-4004
2. Al-Oqla FM, Sapuan SM. 2014. Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry. J Clean Prod 66: 347-354. https://doi.org/10.1016/j.jclepro.2013.10.050
3. Al-Oqla FM, Sapuan SM, Ishak MR, Nuraini AA. 2016. A decision-making model for selecting the most appropriate natural fiber–Polypropylene-based composites for automotive applications. J Compos Mater 50(4): 543-556. https://doi.org/10.1177/0021998315577233
4. Ahmad F, Choi HS, Park MK. 2015. A review: natural fiber composites selection in view of mechanical, light weight, and economic properties. Macromol Mater Eng 300(1): 10-24. https://doi.org/10.1002/mame.201400089
5. Madsen B, Hoffmeyer P, Lilholt H. 2007. Hemp yarn reinforced composites–II. Tensile properties. Compos Part A Appl Sci Manuf 38(10): 2204-2215. https://doi.org/10.1016/j.compositesa.2007.06.002
6. Yao J, Ma L, Lu W, Tan H. 2015. Tensile property analysis and prediction model building for coir rope reinforced unsaturated polyester composite. BioResources 10(1): 697-708.
7. Reddy GV, Naidu SV, Rani TS. 2008. Impact properties of kapok based unsaturated polyester hybrid composites. J Reinf Plast Compos 27(16-17): 1789-1804. https://doi.org/10.1177/0731684407087380

8. Zampaloni M, Pourboghrat F, Yankovich SA, Rodgers BN, Moore J, et al. 2007. Kenaf natural fiber reinforced polypropylene composites: a discussion on manufacturing problems and solutions. Compos Part A Appl Sci Manuf 38(6): 1569-1580. https://doi.org/10.1016/j.compositesa.2007.01.001

9. Sreenivasan VS, Somasundaram S, Ravindran D, Manikandan V, Narayanasamy R. 2011. Microstructural, physico-chemical and mechanical characterisation of Sansevieria cylindrica fibres–an exploratory investigation. Mater Des 32(1): 453-461. https://doi.org/10.1016/j.matdes.2010.06.004

10. Saba N, Paridah MT, Jawaid M. 2015. Mechanical properties of kenaf fibre reinforced polymer composite: a review. Constr Build Mater 76: 87-96. https://doi.org/10.1016/j.conbuildmat.2014.11.043

11. Punyamurthy R, Sampathkumar D, Bennehalli B, Gouda R, Srinivasa CV. 2015. Influence of fiber content and effect of chemical pre-treatments on mechanical characterization of natural abaca epoxy composites. Indian J Sci Technol 8(11): 53236. https://doi.org/10.17485/ijst/2015/v8i11/71768

12. Li X, Tabil LG, Panigrahi S. 2007. Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a review. J Polym Environ 15: 25-33. https://doi.org/10.1007/s10924-006-0042-3

13. Sanjay MR, Madhu P, Jawaid M, Senthamaraikannan P, Senthil S, et al. 2018. Characterization and properties of natural fiber polymer composites: a comprehensive review. J Clean Prod 172: 566-581. https://doi.org/10.1016/j.jclepro.2017.10.101

14. Vinod A, Sanjay MR, Suchart S, Jyotishkumar P. 2020. Renewable and sustainable biobased materials: an assessment on biofibers, biofilms, biopolymers and biocomposites. J Clean Prod 258: 120978. https://doi.org/10.1016/j.jclepro.2020.120978

15. Yoganandam K, Shanmugam V, Vasudevan A, Vinodh D, Nagaprasad N, et al. 2021. Investigation of dynamic, mechanical, and thermal properties of Calotropis procera particle-reinforced PLA biocomposites. Adv Mater Sci Eng 2021: 2491489. https://doi.org/10.1155/2021/2491489

16. Ali KA, Mohanavel V, Ravichandran M, Vendan SA, Sathish T, et al. 2021. Microstructure and mechanical properties of friction stir welded SiC/TiB_2 reinforced aluminum hybrid composites. Silicon 14, 3571-3581. https://doi.org/10.1007/s12633-021-01114-3

17. Alagarsamy SV, Balasundaram R, Ravichandran M, Mohanavel V, Karthick A, et al. 2021. Taguchi approach and decision tree algorithm for prediction of wear rate in zinc oxide-filled AA7075 matrix composites. Surf Topogr 9(3): 035005. https://doi.org/10.1088/2051-672X/ac0f34

18. Kavimani V, Gopal PM, Stalin B, Karthick A, Arivukkarasan S, et al. 2021. Effect of graphene oxide-boron nitride-based dual fillers on mechanical behavior of epoxy/glass fiber composites. J Nanomater 2021: 5047641. https://doi.org/10.1155/2021/5047641

19. Kavimani V, Stalin B, Gopal PM, Ravichandran M, Karthick A, et al. 2021. Application of r-GO-MMT hybrid nanofillers for improving strength and flame retardancy of epoxy/glass fibre composites. Adv Polym Technol 2021: 6627743. https://doi.org/10.1155/2021/6627743

20. Phan NH, Rio S, Faur C, Le Coq L, Le Cloirec P, et al. 2006. Production of fibrous activated carbons from natural cellulose (jute, coconut) fibers for water treatment applications. Carbon 44(12): 2569-2577. https://doi.org/10.1016/j.carbon.2006.05.048

21. Rahman MR, Huque MM, Islam MN, Hasan M. 2008. Improvement of physico-mechanical properties of jute fiber reinforced polypropylene composites by post-treatment. Compos Part A Appl Sci Manuf 39(11): 1739-1747. https://doi.org/10.1016/j.compositesa.2008.08.002

22. Ramesh M, Palanikumar K, Reddy KH. 2013. Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites. Compos Part B Eng 48: 1-9. https://doi.org/10.1016/j.compositesb.2012.12.004

23. Alavudeen A, Rajini N, Karthikeyan S, Thiruchitrambalam M, Venkateshwaren N. 2015. Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: effect of woven fabric and random orientation. Mater Des 66: 246-257. https://doi.org/10.1016/j.matdes.2014.10.067

24. Birat KC, Panthapulakkal S, Kronka A, Agnelli JAM, Tjong J, et al. 2015. Hybrid biocomposites with enhanced thermal and mechanical properties for structural applications. J Appl Polym Sci 132(34): 42452. https://doi.org/10.1002/app.42452

25. Venkateshwaran N, Elayaperumal A, Sathiya GK. 2012. Prediction of tensile properties of hybrid-natural fiber composites. Compos Part B Eng 43(2): 793-796. https://doi.org/10.1016/j.compositesb.2011.08.023

26. Thwe MM, Liao K. 2002. Effects of environmental aging on the mechanical properties of bamboo–glass fiber reinforced polymer matrix hybrid composites. Compos Part A Appl Sci Manuf 33(1): 43-52. https://doi.org/10.1016/S1359-835X(01)00071-9

27. Meon MS, Othman MF, Husain H, Remeli MF, Syawal MSM. 2012. Improving tensile properties of kenaf fibers treated with sodium hydroxide. Procedia Eng 41: 1587-1592. https://doi.org/10.1016/j.proeng.2012.07.354

28. Vilay V, Mariatti M, Taib RM, Todo M. 2008. Effect of fiber surface treatment and fiber loading on the properties of bagasse fiber–reinforced unsaturated polyester composites. Compos Sci Technol 68(3-4): 631-638. https://doi.org/10.1016/j.compscitech.2007.10.005

29. Narendar R, Dasan KP. 2014. Chemical treatments of coir pith: morphology, chemical composition, thermal and water retention behavior. Compos Part B Eng 56: 770-779. https://doi.org/10.1016/j.compositesb.2013.09.028

30. Kim H, Okubo K, Fujii T, Takemura K. 2013. Influence of fiber extraction and surface modification on mechanical properties of green composites with bamboo fiber. J Adhes Sci Technol 27(12): 1348-1358. https://doi.org/10.1080/01694243.2012.697363

31. Edeerozey AM, Akil HM, Azhar AB, Ariffin MZ. 2007. Chemical modification of kenaf fibers. Mater Lett 61(10): 2023-2025. https://doi.org/10.1016/j.matlet.2006.08.006

32. Sharma H, Singh I, Misra JP. 2019. Mechanical and thermal behaviour of food waste (Citrus limetta peel) fillers–based novel epoxy composites. Polym Polym Compos 27(9): 527-535. https://doi.org/10.1177/0967391119851012

33. Singh JIP, Singh S, Dhawan V. 2020. Influence of fiber volume fraction and curing temperature on mechanical properties of jute/PLA green composites. Polym Polym Compos 28(4): 273-284. https://doi.org/10.1177/0967391119872875

34. Vignesh V, Balaji AN, Nagaprasad N, Sanjay MR, Khan A, et al. 2021. Indian mallow fiber reinforced polyester composites: mechanical and thermal properties. J Mater Res Technol 11: 274-284. https://doi.org/10.1016/j.jmrt.2021.01.023

35. Sathish S, Kumaresan K, Prabhu L, Gokulkumar S. 2018. Experimental investigation of mechanical and FTIR analysis of flax fiber/epoxy composites incorporating SiC, Al_2O_3 and graphite. Romanian J Mater 48(4): 476.

36. Gokulkumar S, Thyla PR, Prabhu L, Sathish S. 2019. Measuring methods of acoustic properties and influence of physical parameters on natural fibers: a review. J Nat Fibers 17(12): 1719-1738. https://doi.org/10.1080/15440478.2019.1598913

37. Sanjay MR, Siengchin S, Parameswaranpillai J, Jawaid M, Pruncu CI, et al. 2019. A comprehensive review of techniques for natural fibers as reinforcement in composites: preparation, processing and characterization. Carbohydr Polym 207: 108-121. https://doi.org/10.1016/j.carbpol.2018.11.083

38. Madhu P, Sanjay MR, Jawaid M, Siengchin S, Khan A, et al. 2020. A new study on effect of various chemical treatments on Agave Americana fiber for composite reinforcement: physico-chemical, thermal, mechanical and morphological properties. Polym Test 85: 106437. https://doi.org/10.1016/j.polymertesting.2020.106437