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Thermo-Mechanical Characterization of Jute-Bamboo Hybrid Thermoplastic Polymer Matrix Composites with Different Stacking Sequences for Automobile Applications

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KEYWORDS

Jute;
Bamboo;
Thermo-mechanical characterization;
Sustainable composite;
Light load automobile applications.

ABSTRACT

Natural fiber composites are increasingly replacing synthetic fibers in today's world due to their numerous benefits. The current study focuses on the production and characterization of hybrid composites incorporating jute/bamboo fibers with a variety of stacking sequences created by the hand layup process. Tensile, flexural, impact, and interlaminar shear strength, Shore D hardness, flammability, and water absorption qualities of manufactured stacking sequences were all examined. Thermogravimetric Analysis (TGA) was used to examine the thermal characteristics of the produced composites. The tensile-fractured surface was studied using a scanning electron microscope (SEM). The obtained results revealed that the tensile, impact and flexural strength of the hybridized composite Bamboo/Jute/Jute/Bamboo (BJJB) was better compared to its counterparts. The hybridization of the composites proved beneficial against impact resistance compared to non-hybridized composites. The flammability of the Jute/Jute/Jute/Jute (JJJJ) composite and the thermal stability of the Bamboo/Bamboo/Bamboo/Bamboo (BBBB) composite is found to be better compared to its counterparts. The fracture mechanism involved in the proposed composites is studied with the help of SEM images. The proposed composites are found to be suitable for light load conditions of automobiles and building equipment.

1. Introduction

Composite materials are made up of two or more materials that come together to produce a continuous and well-bonded area at the interface. Composite materials are divided into three categories based on their matrix: polymer, metal, and ceramic matrix composites. Thermoplastic and thermosetting plastics are two different forms of polymer matrix. Owing to their decreased weight and shrinkage, thermosetting polymers are employed in the automobile and home goods industries [1]. Synthetic fibers such as glass, carbon, and aramid fibers reinforced with thermosetting matrix exhibit improved strength but they are not recyclable and sustainable [2,3]. To counter this disadvantage, natural fibers are employed as a replacement material [4]. Natural fibers provide several advantages, including low cost, biodegradability, and accessibility [4–7]. Natural fiber mats are offered in both unidirectional and bidirectional weaves. By stacking different types of fibers and calling them hybridization, these natural fibers may be mixed to make composites[8,9]. These hybrid composites include reinforcements that are a combination of synthetic fibers, natural fibers, or also a combination of synthetic and natural fibers. Because of their enhanced strength-to-weight ratio, these hybrid composites may be utilized in a variety of technology sectors. Woven fibers in a single direction are known to provide more strength compared to fibers woven in two directions [10]. The mechanical properties of aloe vera and sisal hybrid composites were investigated. Hybrid composites have good mechanical properties, according to their research [11,12]. Researchers have examined the use of jute-reinforced composites using a

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variety of natural and synthetic resin components [13,14] to assess their mechanical properties. Also, the behavior of alkali-treated jute-reinforced composites for different loadings is assessed at different temperatures [15].

Automotive components have successfully utilized jute-reinforced composites [16–18]. Jute and glass fiber were hybridized, and a thermo-mechanical analysis of the results showed that the hybridization resulted in improved thermo-mechanical properties [19].

Bamboo (Bambusabambos) is an anisotropic material with directional mechanical characteristics. Bamboo is one of the most rapidly growing, conveniently available, ecologically beneficial, and renewable goods among many natural resources [20]. An extensive literature search revealed that there has been a study on natural fibers with various stacking sequences.

The jute/bamboo fiber stacking sequence has no known works. As a result, the current research focuses on the hand layup technique for producing jute/bamboo fibers in various sequences. The proposed stacking sequence's mechanical and physical properties were investigated. TGA investigated the thermal properties of the produced composites. The fractured surfaces were examined to assess the mode of failure in the proposed composites.

2. Materials and Methods

The present section describes the selection of materials, manufacturing methods used, and characterization techniques.

2.1. Materials

The present study makes use of Polypropylene (PP) as a matrix. The PP was supplied by Polyolefin Company Pvt., Ltd., Singapore. The PP has a density of 0.905 g/cm^3 at room temperature and the melting temperature (T_m) and melt flow indexes are 160°C and 6 g/10 min., respectively Jute (average fiber's density of 1.163 g/cm^3, and the unit area weight of 957 g/m^2 with a tensile strength ranging from 331-414 MPa) and bamboo (bamboo fiber's density: 1.293 g/cm^3, and the unit area weight of 907 g/m^2 with a tensile strength ranging from 615-862 MPa) in the form of woven mat obtained from Go Green products, Chennai, India is used as fiber reinforcement in the proposed composite.

Table 1 provides the configurations and stacking sequence details of the composites used in the present study. The schematic of the proposed composites is presented in Figure 1.

Table 1. Composites used in the present study

Composite designation	Stacking sequences
JJJJ	Jute/Jute/Jute/Jute
BBBB	Bamboo/Bamboo/Bamboo/Bamboo
JBBJ	Jute/Bamboo/Bamboo/Jute
BJJB	Bamboo/Jute/Jute/ Bamboo

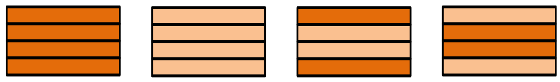

Fig. 1. Schematic of proposed composites

2.2. Fabrication

The thermoforming procedure was used to create the proposed composites. To eliminate moisture, the jute and bamboo textiles were put in an oven at 80°C for 1 hour. Jute, bamboo cloth, and PP film were alternately layered and inserted into the mold cavity.

The laminate was wrapped in a vacuum bag and vacuumed for 30 minutes to remove the air from the assembly. Following that, a caul plate of the aluminum block was placed on top of the laminate and heated to 160^{0}C on a hot press machine for 45 minutes. The PP film will melt at this stage, and the laminate's thickness may decrease. As a result, the hot press must be set such that the laminate touches the hot plates during heating. After the PP film was melted, a compression pressure of 1.7 MPa was used to compact the laminate. Finally, the laminate within the mold was allowed to cool naturally on the hot press for 12 hours.

2.3. Testing

An automated universal testing machine having a capacity of 10 KN was used to evaluate the tensile strength and flexural strength of the proposed composites according to ASTM D638-14 and ASTM D790-17 standards respectively. Computerized impact testing equipment was used to assess the impact strength of the produced composites. The force used was 6 J, and the test was conducted according to ASTM D256-10. According to ASTM D570-98, the water absorption of the produced composites was investigated. The water absorption test samples were split into 50x50x 10 mm^3 pieces. The hardness of the produced composites was determined using ASTM D2250-15 Shore D hardness. The interlaminar shear test was performed according to ASTM D2234. ASTM D635 was used to determine the flammability of the produced composites. Thermal characterization was carried out using TGA. From 30 degree Celsius to 600 degrees Celsius, the samples were warmed at a rate of 10 degree

Celsius per minute. SEM was utilized to analyze the fractography of the fractured part of the tensile specimen.

3. Results and Discussion

In manufactured jute/bamboo fiber samples, the mechanical and physical properties were assessed. The average of the result obtained from five repetitions for each of the tests is taken as the final result. The overall view of the results obtained is presented in Table 2.

3.1. Tensile Strength

Any composite's tensile strength is determined by elements like the strength of the fiber, modulus, fiber stacking orientation, and matrix-fiber bonding. How cracks form and spread affects whether or not the tensile test fails. The properties of tensile strength are shown in Figure 2.

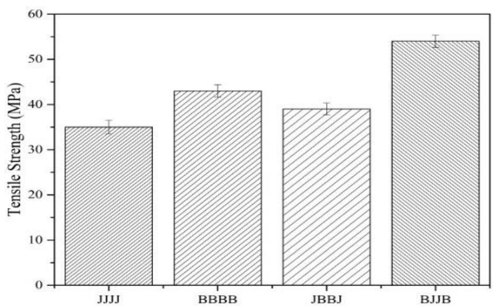

Fig. 2. Tensile strength of proposed composites

The hybrid composite with stacking sequence BJJB has the highest tensile strength among the suggested composites, followed by BBBB, JBBJ, and JJJJ. BJJB has a tensile strength of 54 MPa, which is 54.28 percent more than the JJJJ composite. The tensile strength of manufactured composites is mostly governed by the cellulose and hemicellulose content of the fiber. Due to the increased degree of polymerization, there was an increase in stress resistance when the cellulose concentration was high.

Bamboo fiber showed the greatest cellulose content in this investigation when compared to jute fiber. The sample BJJB is composed of jute fiber in the center and bamboo at the extreme layers, which has the greatest cellulose content and hence the maximum tensile strength. The tensile strength of any hybrid fiber is determined by the strength of each reinforced fiber. The inclusion of bamboo at the exterior layers led to enhanced tensile properties.

The distribution of stresses is facilitated by jute fiber which is placed at the inner layers. The fiber and matrix that were used to make the composites largely determined their strength. The superior bond between the inner layer of jute fiber and the outside skin layer of bamboo was what gave the material its greater tensile strength. Another factor responsible for the enhanced tensile strength of BJJB composites was the excellent bonding between the matrix and the fiber.

The findings of mechanical properties for stacking sequences of kenaf/coir fibers with more cellulose in the outer layer were in line with the tensile strength mentioned [21]. Tensile strength was reduced due to a lack of suitable bonding between the matrix and the fiber. A comparable decline in tensile strength characteristics was seen when an improper coupling between the fiber and the matrix was present [22]. As a result, the BJJB sample may be able to withstand the highest strength.

3.2. Flexural strength

The flexural strength of the composites is presented in Figure 3.

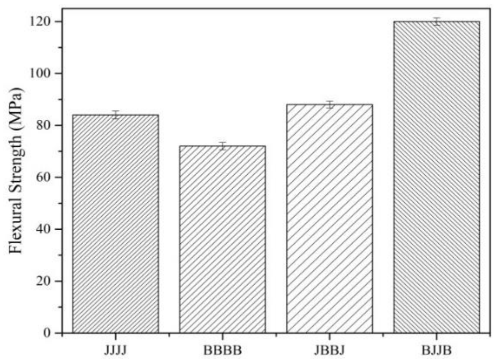

Fig. 3. Flexural strength of proposed composites

Table 2. Overview of Thermo mechanical properties of proposed composites

Composite designation	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J/mm)	Interlaminar shear strength (MPa)	Shore D hardness	Flammability (mm/min)	Water absorption (%)
JJJJ	35	84	0.21	10.06	18	13	9.75
BBBB	43	72	0.23	4.73	25	21	7.8
JBBJ	39	88	0.30	13.55	19	17	8.23
BJJB	54	120	0.38	24.62	21	19	8.05

Composite with stacking sequence BJJB has a flexural strength of 120 MPa which is the maximum among the suggested composites, followed by JBBJ (88 MPa), JJJJ (84 MPa), and BBBB (72 MPa). BJJB has 66.66 percent greater flexural strength than JJJJ composite. The flexural strength of any composite may be increased by inserting stiffer fibers at the outer layers. As a result, in the case of BJJB composite, bamboo fiber, which is stiffer than jute fiber, is used as the outer fiber. As a result, it has the greatest flexural strength. When the matrix and fiber were properly bound, the stiffness of the composites increased. Flexural strength improvements of similar magnitude have been observed as a result of excellent matrix-fiber bonding [23]. The loss of flexural strength in other produced composites was caused by inadequate bonding between the fiber and the matrix.

3.3. ILSS

Any composite's ILSS is affected by the existence of vacancies and how well the constituents adhere to each other. Parameters of the composites' ILSS are shown in Figure 4.

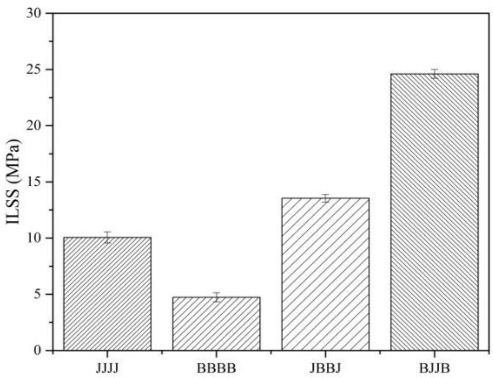

Fig. 4. Interlaminar shear strength of proposed composites

The composite BJJB has the maximum ILSS of 24.62 MPa among the suggested composites, followed by JBBJ (13.55 MPa), JJJJ (10.06 MPa), and BBBB (4.73 MPa). BJJB has 5.2 times the ILSS of BBBB. When the matrix and fiber interaction was stronger, ILSS increased. The composites' shear strength was decreased as a result of the holes and gaps that caused the composites to break more quickly. The ILSS of BBBB composites was reduced by the addition of additional voids and cracks.

3.4. Impact Strength

Impact strength is determined by both the fiber properties and the matrix-fiber adhesion. Figure 5 depicts the impact strength of the suggested composites.

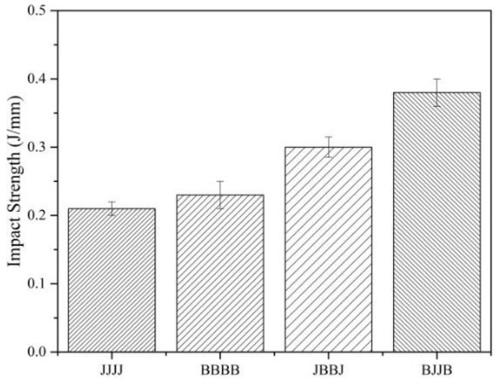

Fig. 5. Impact strength of proposed composites

The graph clearly shows that non-hybridized composites (JJJJ and BBBB) have lower impact strength than hybridized composites (JBBJ and BJJB). This is because pure composites have the same shock-bearing capabilities in all directions, resulting in less resistance to the applied load. As a result of the findings, it is obvious for the fibers to be hybridized to get improved resistance against impact. Figure 4 demonstrates an increase in impact strength caused by the hybridization of jute and bamboo fibers. The impact strength of the BJJB samples was the greatest of all the composites developed. The addition of bamboo to the outer layer improved the impact properties.

3.5. Water Absorption

Natural fibers absorb moisture, causing the composites to expand because they are composed of hydrophilic constituents that can absorb water. Composites' water absorption capabilities have been widely examined to discover how much water a certain sample absorbs under specific situations. A lot of characteristics influence it, including the fiber volume percentage, matrix viscosity, and the existence of holes. Figure 6 shows the water absorption behaviour of the proposed composites.

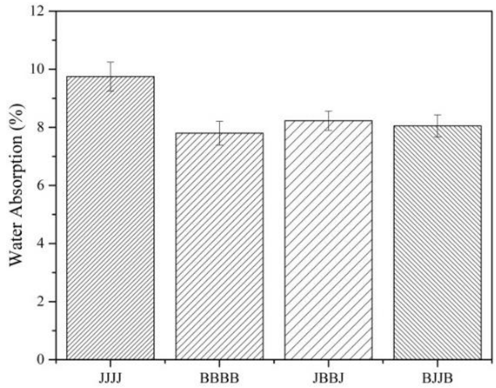

Fig. 6. Water absorption of proposed composites

Tensile strength properties are inversely correlated with water absorption features. BJJB has lower absorption qualities than other composites because the matrix and fibers are better linked. Because the gaps had previously been filled during the production process, this demonstrated that the fiber packing and design would restrict moisture accumulation in the composites. Because of the presence of pores and fiber pullout, the composites with the lowest tensile strength will have greater swelling, leading to reduced tensile strength.

3.6. Shore D hardness and flammability

Shore D hardness describes a sample's resistance to indentation which is determined by its stiffness. Figure 7 depicts the shore D hardness values of the built samples.

The composite BBBB had the highest hardness in this investigation, followed by BJJB, JBBJ, and JJJJ. This is because bamboo is a stiffer fiber than jute.

When polymers are heated, they go through thermo-oxidative thermal breakdown. The chemical and physical properties of the fibers influence the rate at which the polymer decomposes. The cellulose content of the selected fiber is directly proportional to its flammability. Heat transfer was hindered by the quantity of lignin in the fiber. Figure 6 displays the flammability of the composites created.

Jute and bamboo fibers have nearly the same hemicellulose content; however, lignin in jute is much greater than in bamboo. Another aspect that adds to the flammability of the composite is the presence of moisture content. Jute has the highest moisture content among the fibers chosen, which minimizes flammability. As a result, JJJJ has lesser flammability than BBBB composite. JJJJ has a 61.5 percent higher flammability than BBBB.

3.7. TGA

Thermogravimetric analysis was used to test the manufactured samples' thermal stability at higher temperatures. Thermal behavior is affected by the presence of moisture, hemicellulose, lignin, wax, and cellulose in the composite. Figure 8 illustrates a relationship between temperature and weight percentage at that point after all samples were heated in the aluminum pan at a rate of 20 degrees per minute. Figure 8 depicts the samples' degradation in two stages.

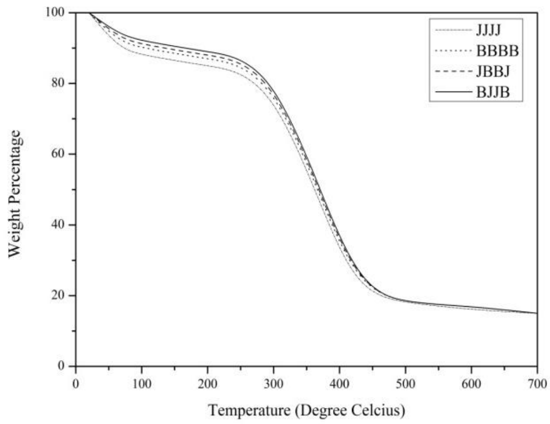

Fig. 8. TGA graphs of proposed composites

The graph clearly showed that there were four stages to weight loss. The sample's moisture content decreased between 20°C and 100°C, which contributed to the first stage of weight loss. The second stage saw weight reduction as a result of the breakdown of the hemicellulose. It took place between 210°C and 270°C. At temperatures ranging from 220°C to 450°C, all of the samples rapidly deteriorated. The next stage was the cellulose content degradation, which began at 300°C and progressed to 410°C.

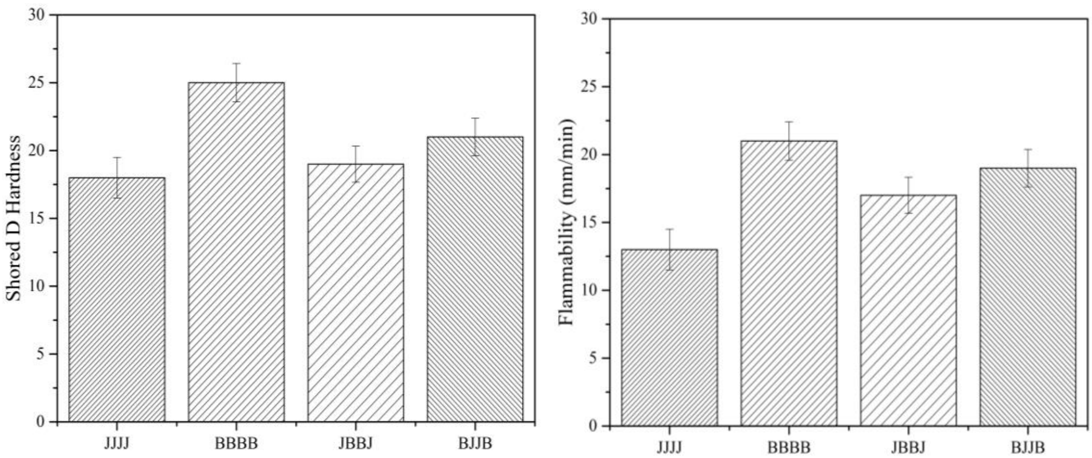

Fig. 7. Shore D hardness and flammability of proposed composites

At this moment, the most weight was lost, and the graph became fairly steep. An intricate process precedes the disintegration of natural fiber composites. It is governed by the thermal stability of the natural fiber, the qualities of the matrix, and the test conditions. In the last stage of degradation, the lignin content was degraded from 410°C to 700°C, which was very difficult to break down and hence took longer. Finally, the remainder was shaped like a char. JJJJ and BBBB exhibit equivalent degradation patterns, while JBBJ and BJJB have comparable patterns. It took longer because the third phase exhibited enhanced content of cellulose. Sample JJJJ with minimal hemicellulose concentration takes less time in the second phase.

Although all of the samples decomposed identically, BBBB having bamboo fiber in both the interior and exterior layers, exhibited somewhat superior stability under thermal load than the others because of the presence of enhanced cellulose and crystalline structure. The increased thermal stability of sample BBBB was also related to its lower lignin content.

3.8. SEM

Figure 9 shows that the composite, JJJJ, has a greater number of holes and voids, resulting in more water absorption. Furthermore, hybridization has improved bonding between the fiber and matrix, minimizing pores and void content. When compared to non-hybrid composites, the mode of failure in hybrid composites is fiber pull-out and matrix cracking at a lower intensity.

4. Conclusions

The current work investigates the fabrication of non-hybrid and hybrid composites using jute and bamboo fibers, as well as the effect of stacking sequence on the thermo-mechanical characteristics of the suggested composites.

From the current study, it is found that BJJB has a 54.28 percent higher tensile strength than the JJJJ composite. When the cellulose content was high, there was an increase in stress resistance due to the higher degree of polymerization. Another factor for the increase in tensile strength properties in BJJB composites was the excellent bonding between the matrix and the fiber. BJJB has 66.66 percent greater flexural strength than JJJJ composite. Bamboo fiber, which is stiffer than jute fiber, is used as the outer fiber in BJJB composites, resulting in increased flexural strength. BJJB has the highest interlaminar shear strength, which is 5.2 times that of the BBBB composite. It was discovered that when the matrix and fiber connection was stronger, inter-laminar shear strength increased. It was discovered that non-hybridized composites (JJJJ and BBBB) have lower impact strength than hybridized composites (JBBJ and BJJB). This is because pure composites have the same shock-bearing capabilities in all directions, resulting in less resistance to the applied load. Thus, it is proved that hybridization leads to enhanced resistance to impact. Water absorption is discovered to be inversely linked to tensile strength characteristics. BJJB has lesser absorption qualities than comparable composites on the market. Because the voids had previously been filled during the production process, this demonstrated that the fiber packing and design would restrict moisture accumulation in the composites. The cellulose concentration of the selected fiber was found to have a direct link with its flammability, while the quantity of lignin in the fiber impeded heat conduction. When compared to BBBB composite, JJJJ has a lesser flammability. JJJJ has a 61.5 percent higher flammability than BBBB. The BBBB sample, which contains bamboo fiber in both interior and exterior layers, was shown to have somewhat superior stability from a thermal aspect than the others due to a higher cellulose content and crystalline structure.

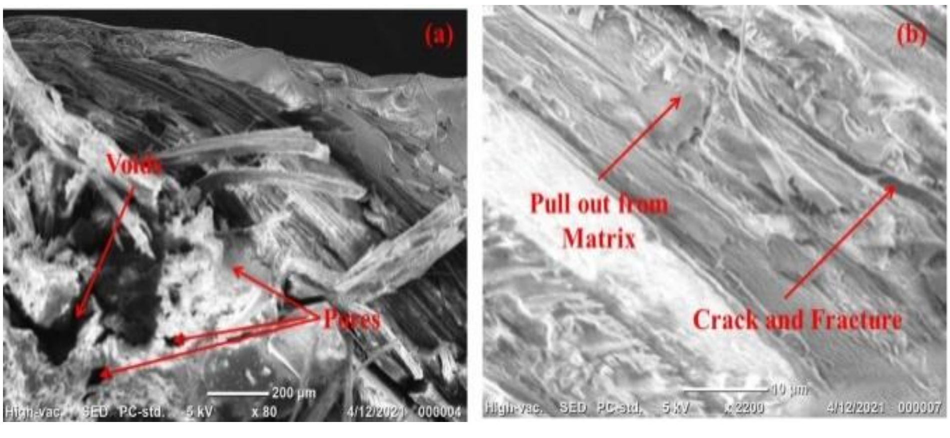

Fig. 9. Fracture mechanisms of the hybrid and non-hybrid composites

The increased thermal stability of sample BBBB was also related to its lower lignin content. SEM image analysis demonstrated that hybridization improved bonding between the fiber and matrix, minimizing pores and void content. This is corroborated by the study's mechanical characterization results. The proposed composite thus exhibits the potential to be used as a bumper in the automobile. The study's future scope can be expanded by investigating its sound absorption qualities, which might potentially replace synthetic materials employed in this industry.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the author have entirely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

References

[1] Daniel, D.J., Panneerselvam, K., 2018. Abrasive wear of polypropylene/Cloisite 30B/Elvaloy AC 3427 nanocomposites. *Journal of Composite Materials, 52*, pp.1833-1843. https://doi.org/10.1177/0021998317734624.

[2] Mahesh, V., Joladarashi, S., Kulkarni, S.M., 2021. Comparative study on ballistic impact response of neat fabric, compliant, hybrid compliant and stiff composite. *Thin Walled Structures 165*, pp. 107986. https://doi.org/10.1016/j.tws.2021.107986.

[3] Mahesh, V., Joladarashi, S., Kulkarni, S.M., 2019. Physio-mechanical and wear properties of novel jute reinforced natural rubber based flexible composite. *Material Research Express, 6*, pp. 1-16. https://doi.org/10.1088/2053-1591/ab0164.

[4] Mahesh, V., Joladarashi, S., Kulkarni, S.M., 2021. Three body abrasive wear assessment of novel jute/natural rubber flexible green composite. *Journal of Thermoplastic Composite Materials*, pp. 1–11. https://doi.org/10.1177/08927057211017185.

[5] Supreeth, S., Vinod, B., Sudev, L.J., 2014. Influence of Fiber Length on the Tribological Behaviour of Short PALF Reinforced Bisphenol-A Composite, *International Journal of Engineering Research and General Science, 2,* pp. 825–830.

[6] Mahesh, V., Mahesh, V., Nagaraj, S.M., Subhashaya, P., Shambu Singh, G.S.T., 2022. Physio-mechanical and thermal characterizati.on of jute/rubber crumb hybrid composites and selection of optimal configuration using the MADM approach, *Proceedings of Institute of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 236(14)*, pp. 7942-7952, https://doi.org/10.1177/09544062221079166.

[7] Mahesh, V., Joladarashi, S., Kulkarni, S.M., 2020. Damage mechanics and energy absorption capabilities of natural fiber reinforced elastomeric based bio composite for sacrificial structural applications, *Defence Technology, 17*, pp. 161–176. https://doi.org/10.1016/j.dt.2020.02.013.

[8] Mahesh, V., Joladarashi, S., Kulkarni, S.M., 2019. Experimental Study on Abrasive Wear Behaviour of Flexible Green Composite Intended to Be Used as Protective Cladding for Structures, *International Journal of Modern Manufacturing Technology, 11*, pp.69–76.

[9] Rostamiyan, Y., Fereidoon, A., Rezaeiashtiyani, M., Mashhadzadeh, A.H., Salmankhani, A., 2015. Experimental and optimizing flexural strength of epoxy-based nanocomposite: Effect of using nano silica and nano clay by using response surface design methodology, *Materials and Design, 69*, pp. 96–104. https://doi.org/10.1016/j.matdes.2014.11.062.

[10] Gupta, M.K., Srivastava, R.K., 2014. Tensile and Flexural Properties of Sisal Fiber Reinforced Epoxy Composite: A Comparison between Unidirectional and Mat form of Fibers. *Procedia Materials Science, 5,* pp. 2434–2439. https://doi.org/10.1016/j.mspro.2014.07.489.

[11] Shadrach Jeya Sekaran, A., Palani Kumar, K., Pitchandi, K., 2015. Evaluation on mechanical properties of woven aloevera and sisal fiber hybrid reinforced epoxy composites, *Bulletin of Materials Science, 38*, pp. 1183–1193. https://doi.org/10.1007/s12034-015-

0999-4.

[12] Feng, N.L., DharMalingam, S., Zakaria, K.A., Selamat, M.Z., 2017. Investigation on the fatigue life characteristic of kenaf/glass woven-ply reinforced metal sandwich materials. *Journal of Sandwich Structural Materials, 21,* pp. 2440–2455. https://doi.org/10.1177/1099636217729910.

[13] Prabaharan Grcaeraj and Venkatachalam., 2015. Investigations Into Tensile Strength of Jute Fiber Reinforced Hybrid Polymer Matrix Composites. *Engineering Review, 35,* pp. 275–281.

[14] Militello, C., Bongiorno, F., Epasto, G., Zuccarello, B., 2020. Low-velocity impact behaviour of green epoxy biocomposite laminates reinforced by sisal fibers. *Composite Structures, 253:112744*. https://doi.org/10.1016/j.compstruct.2020.112744.

[15] Jabbar, A., Militký, J., Madhukar Kale, B., Rwawiire, S., Nawab, Y., Baheti, V., 2016. Modeling and analysis of the creep behavior of jute/green epoxy composites incorporated with chemically treated pulverized nano/micro jute fibers. *Industrial Crops and Production, 84*, pp. 230–240. https://doi.org/10.1016/j.indcrop.2015.12.052.

[16] Alves, C., Ferrão, P.M.C., Silva, A.J., Reis, L.G., Freitas, M., Rodrigues, L.B., 2010. Ecodesign of automotive components making use of natural jute fiber composites. *Journal of Cleaner Production, 18,* pp. 313–327. https://doi.org/10.1016/j.jclepro.2009.10.022.

[17] Pflug, J., Fan, X.Y., Vangrimde, B., Verpoest, I., Bratfisch, P., Vanderpitte, D., 2002. Development of a sandwich material with polypropylene/natural fiber skins and paper honeycomb core. In Proceedings of 10th Eur Conference on Composite Materials.

[18] Mahesh, V., Joladarashi, S., Kulkarni, S.M., 2022. An experimental study on adhesion, flexibility, interlaminar shear strength, and damage mechanism of jute/rubber-based flexible “green” composite. *Journal of Thermoplastic Composite Materials, 35(2),* pp. 149-176, https://doi.org/https://doi.org/10.1177/0892705719882074.

[19] Braga, R.A., Magalhaes, P.A.A., 2015. Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites. *Materials Science and Engineering: C, 56,* pp. 269–273. https://doi.org/10.1016/j.msec.2015.06.031.

[20] Jackson Singh, T., Samanta, S., Singh, H., 2017. Influence of Kevlar Hybridization on Dielectric and Conductivity of Bamboo Fiber Reinforced Epoxy Composite. *Journal of Natural Fibers, 14,* pp. 837–845. https://doi.org/10.1080/15440478.2017.1279583.

[21] Islam, M.S., Hasbullah, N.A.B., Hasan, M., Talib, Z.A., Jawaid, M., Haafiz, M.K.M., 2015. Physical, mechanical and biodegradable properties of kenaf/coir hybrid fiber reinforced polymer nanocomposites. *Materials Today Communication, 4,* pp. 69–76. https://doi.org/10.1016/j.mtcomm.2015.05.001.

[22] Jafrey Daniel, D., Sai Krishnan, G., Velmurugan, P., 2019. Investigation on the characteristics of bamboo/jute reinforced hybrid epoxy polymer composites. *Materials Research Express, 6*. https://doi.org/10.1088/2053-1591/ab3ae7.

[23] Nampoothiri, E.N., Bensam Raj, J., Thanigaivelan, R., Karuppasamy, R., 2022. Experimental Investigation on Mechanical and Biodegradation Properties of Indian Almond–Kenaf Fiber-Reinforced Hybrid Composites for Construction Applications. *Journal of Natural Fibers, 19(1),* pp. 292-302. https://doi.org/10.1080/15440478.2020.1739592.