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RESEARCH ARTICLE

Fabrication and mechanical characterization of sisal fiber, banana fiber and bamboo strip reinforced hybrid composite

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Abstract

This study investigates the effect of sisal fiber content on the mechanical properties of composite materials, specifically focusing on tensile strength, flexural strength, and impact strength. The results show a clear trend: as the sisal fiber content increased, the tensile strength of the composites decreased. Sample 1, which had the least amount of sisal fiber, achieved the highest tensile strength of 39.616 MPa, while Sample 2 and Sample 3 exhibited tensile strengths of 28.763 MPa and 20.965 MPa, respectively. A similar decline in flexural strength was observed, with Sample 1 showing the highest flexural strength of 69.933 MPa, and Sample 2 and Sample 3 showing 62.259 MPa and 47.707 MPa, respectively. In contrast, the impact strength increased with higher sisal fiber content. Sample 1 exhibited an impact strength of 101.7372 KJ/m², which increased to 124.5539 KJ/m² in Sample 2 and 128.3414 KJ/m² in Sample 3. The findings highlight a trade-off between strength and toughness: while increasing sisal fiber content improves impact strength, it significantly reduces tensile and flexural strengths. This suggests that optimizing the fiber content is essential depending on the intended application. For applications requiring impact resistance, higher fiber content is preferred, while for those needing high tensile and flexural strength, lower fiber content is more suitable.

1. Introduction

Natural fibres are gaining importance in the burgeoning green economy. Natural fibres are abundant renewable resources in nature. Natural fibres are carbon neutral because they absorb the same amount of Carbon dioxide that they emit. Natural fibres like jute, banana, sisal, coir, and others are completely renewable, environmentally friendly, have a high specific strength, are nonabrasive, are very cheap, and are biodegradable. These properties have recently piqued the interest of natural fibre researchers. Since bananas are grown by farmers all over the world, banana fibres are widely available as agricultural waste. These wastes are biodegradable and environmentally friendly, as well as having a low cost, lightweight, low density, and high tensile strength. They can be used for a variety of purposes. During the last few decades, composites research has produced excellent engineering materials. Many composite materials have demonstrated their utility and are now ready to replace other materials. The introduced polymer resin matrix materials also performed well as a matrix.

A study to investigate the properties and potential applications of a composite material made from Aloe vera and jute, as reinforcement materials in epoxy-based composite laminates. HY951 hardener and LY556 Epoxy resin were used as the matrix and hardener, respectively. The

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results of the study showed that the ultimate tensile strength (UTS) and flexural strength of the Aloe vera laminate were slightly higher than that of the jute fiber. However, the drop impact test results showed that the three samples had similar behavior. Moreover, the thermal conductivity of the aloe vera/jute hybrid laminates is almost the same as that of Aloe vera laminates. However, it is higher by 13.65% than that of the jute fiber alone. Overall, the study suggests that Aloe vera and jute fibers can be used as potential reinforcement materials in epoxy-based composite laminates. The results indicate that Aloe vera has slightly better mechanical properties than jute fiber, while the thermal conductivity of the hybrid jute/aloe vera laminate is higher than that of jute fiber alone. These findings could have significant implications for the development of new, environmentally friendly composite materials with improved mechanical and thermal properties. [1, 2]. Banana and bagasse fibers were used as reinforcement materials for composite fabrication. The chemical treatment of fiber with NaOH and NaCl solutions of 5% concentration to improve their mechanical properties. The volume fractions of the fibers used were 20% and 30%, and they were used in equal proportions for fabrication using the hand layup method. By these improved adhesion properties observed. 30% volume fraction has harder than the 20% volume fraction. [3]. Hybrid composites are indeed fabricated by the combination of two or more fiber in single matrix. The properties of the composite material can be affected by several factors, including the variation in fiber volume or weight fraction, variation in the stacking sequence of fiber layers, fiber treatment, and environmental conditions., extreme fiber layer and treatment of fiber by NaOH [4]. hybrid composites were fabricated using combinations of banana/bamboo, pineapple/bamboo, banana/pineapple, and bamboo/ banana/ pineapple. The composites were manufactured by using the hand layup technique, with 70% resin and 30% fiber [5]. A composite material was fabricated using banana and sisal fibers and an epoxy resin. The chemical treatment of fiber is conducted with 5% NaOH solution, and the resin and hardener were mixed in appropriate volumes. The composite was prepared using the hand layup technique, with 30g of epoxy and hardener used for each sample. Additionally, an excessive amount of hardener was found to lead to brittleness in the composite material. Interestingly, the study found that a composite made with 80% sisal and 20% banana fiber had higher strength values than a composite made with an equal proportion of both fibers (50% sisal and 50% banana). This suggests that the specific ratio of fibers used in the composite can have a significant impact on its mechanical properties. Banana fiber is known for its smooth surface finish, and combining it with sisal fiber could lead to a composite material with both good strength and a desirable surface finish [6]. Sisal and banana fibre are used for composite with alkali treatment by 15% Ca (OH)2. Here compression molding method are used for fabrication. Three sample are made, S/B/S (untreated), B/S/B (treated), S/B/S (treated) with 40% volume of Epoxy matrix. Tensile and impact test show good result for S/B/S(treated) and flexural test show good result for S/B/S(untreated) [7] Three different composites were fabricated using jute fiber, banana fiber, and a hybrid combination of jute and banana fibers. The jute composite had 20% jute fiber, the banana composite had 10% banana fiber, and the hybrid composite had 15% jute and 15% banana fiber. All composites were treated with 3% potassium permanganate to improve their wettability, and polyester resin was used along with 3% cobalt naphthenate for curing and 5% methyl ethyl ketone peroxide. The composites were manufactured using the hand lay-up technique and applying compression jute fiber was made into the length of 4 cm of length and Banana fiber is made into 5 cm long fiber. 30% Volume fraction hybrid composite shows higher increase in mechanical properties than the non-hybrid composite. While potassium Permanganate treatment increases tensile and flexural strength but not show any improvement in impact test [8]. Various work was done on aluminum and synthetic fiber [9, 10]. Kenaf fiber was used as a reinforcement material for composite fabrication using the vacuum-assisted resin transfer molding (VARTM) process with cold pressing. The process involved infusing unsaturated polyester resin into the preforms under a vacuum pressure of 1.3-1.6 kPa. The resulting composite was analyzed using dynamic mechanical analysis (DMA), which revealed that the moduli of the VARTM composite were doubled in the temperature range of -50 °C to 200 °C compared to the un-reinforced polyester matrix. This indicates that the kenaf fiber reinforcement greatly improved the stiffness and strength of the composite over a wide temperature range [11]. Based upon literature survey, it can be seen that most of the researchers have used Sisal/Banana or Sisal/Bamboo for fabrication the composite. Scarce literature is available on the combination of Sisal, Banana, and Bamboo together as all these three fibers have good mechanical properties and they can be stack together in single composite with better properties.

2. Materials And Methods

In hybrid composite material we are using banana, bamboo and sisal fibers as reinforcement and epoxy(resin) as a base(matrix) material having low viscosity. We are using bamboo cross link mat, sisal and banana fibres and find effect on mechanical property of composite material on different composition like Sisal, Banana and Bamboo, Epoxy resin and hardener, Silica gel, Acetone, and NaOH.

2.1 Sisal Fibre

Sisal fiber is procured from fiber region, Chennai (India) shown in Fig. 1a. Sisal fiber is a natural fiber that is derived from the leaves of the sisal plant, which belongs to the Agavaceae family. Sisal fiber has also gained attention as a potential reinforcement material for use in composite materials due to its desirable mechanical properties.

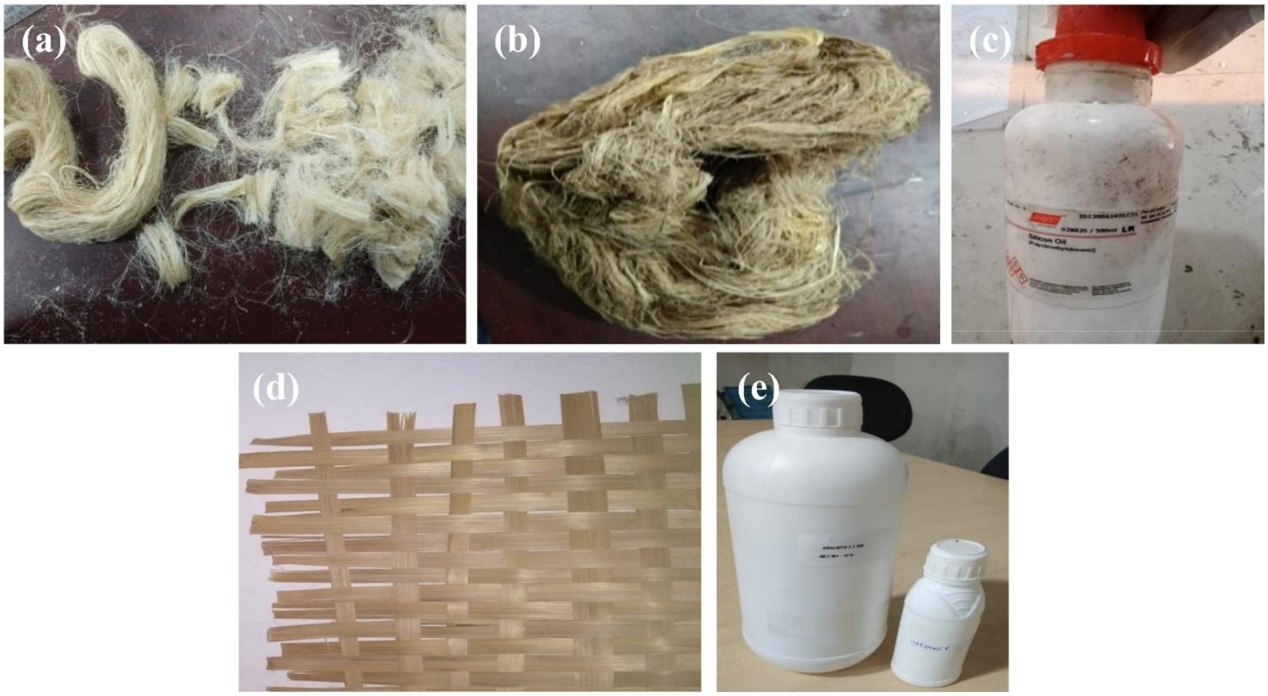

Figure 1: Sisal Fibre, (b) Banana Fibre, (c) Bamboo strip, (d) Epoxy and Hardener, (e) Acetone

Banana fiber was sourced from the Fiber Region, Chennai (India), using mature banana pseudo-stems as shown in Fig. 1b. Bamboo strips were obtained from the local market in Gorakhpur (India), as depicted in Fig. 1c. The composite construction involved the use of Epoxy resin LY 556 and hardener HY 951. When combined, these resins provide excellent chemical and moisture resistance, along with exceptional electrical insulating properties. To facilitate easy removal of the composite after fabrication, silicon oil (Poly(dimethylsiloxane)) was used as a lubricant between the polymer sheet and the composite interface. Acetone, with a density of 0.7 gm/cc, was employed as a solvent to clean epoxy residue from the beaker and brushes. Sodium hydroxide (NaOH), also known as caustic soda, was used in the fiber treatment process. NaOH comes in various forms, including flakes, pellets, granules, and solutions. In this study, a 5% NaOH solution was used for alkali treatment. The fibers, which contain hydroxyl groups that hinder proper bonding with the matrix, were immersed in the solution for 24 hours to enhance the bonding strength. This treatment also removed impurities such as lignin and wax, increasing the fibers' aspect ratio. Afterward, the fibers were washed 3-4 times with distilled water to remove any remaining chemicals.

3. Fabrication Method

Hand layup is a widely used process in the manufacturing of composite materials like fiberglass, carbon fiber, or Kevlar. In this method, composite material is manually laid onto a mold or tool surface and cured to form a solid part. The process begins with preparing the mold, which involves cleaning the mold or tool surface to remove any contaminants and ensure proper adhesion. The composite material is then cut into the desired shape and size using cutting techniques like sawing. Next, a layer of resin is applied to the mold surface using a brush or roller. The composite material is placed on the resin-coated mold and pressed to ensure good contact. Additional layers of composite material and resin are added to achieve the desired thickness and strength, followed by curing the composite at room temperature or with heat. After curing, the composite part is removed from the mold and any excess material is trimmed off.

Hand layup is commonly used in the production of composite products such as boat hulls, aircraft parts, wind turbine blades, and sports equipment. While it is a relatively simple process, it requires skilled workers to ensure precision and consistency. In this study, after alkali treatment, sisal and banana fibers were chopped into 5 cm lengths, and bamboo strips were made into mats. The hand layup method was used for fabrication, where epoxy and hardener were mixed in a 10:1 ratio and stirred for 10-15 minutes to create a homogeneous mixture. A PVC sheet was then fixed onto an acrylic sheet with cello tape, and a thin coat of silicon oil (separator) was applied to the sheets. The first layer of the epoxy-hardener mixture was applied to the PVC sheet using a brush, covering the size of the bamboo mat (300mm x 300mm). Resin mixture was spread onto the first layer of bamboo mat using a roller. A mixture of chopped sisal and banana fibers was added on top, and the roller was used to ensure uniform spreading. A final layer of the epoxy-hardener mixture was applied over the bamboo mat, and a PVC sheet coated with silicon oil was placed on top. The sample was then placed under a hydraulic press for 24 hours to complete the curing process.

3.1 Mechanical Testing

Mechanical testing plays a crucial role in material characterization, with three commonly used tests to assess the mechanical properties of materials: tensile, flexural, and impact testing. Tensile testing evaluates a material's strength and ductility by applying a gradually increasing force until the material breaks or fractures. Flexural testing measures the strength and stiffness of a material under bending loads, while impact testing determines a material's ability to absorb energy and resist fracture or deformation when subjected to sudden shocks or impacts.
In this study, mechanical properties were tested in accordance with ASTM standards. Tensile testing followed ASTM D638, conducted at a feed rate of 5 mm/min. Flexural testing was performed according to ASTM D790 at a feed rate of 2 mm/min. Both tests were carried out using an Instron-1195 universal testing machine, which has a maximum load capacity of 100 kN. Impact testing was conducted using a Zwick impact testing machine, and the sample was prepared according to ASTM D256. These tests were carried out to determine the optimal material combination that provides the best mechanical strength and fire-wearing capacity.

4. Results and Discussion

Tensile testing is a crucial method used to evaluate the strength and ductility of materials. In this study, tensile testing was performed to investigate the effect of sisal fiber content on the tensile strength of the composite. The results show that as the amount of sisal fiber increased, the tensile strength of the composite material decreased. The first sample (Sample 1), which contained the least amount of sisal fiber, exhibited the highest tensile strength of 39.616 MPa. As the percentage of sisal fiber was increased in the subsequent samples, the tensile strength dropped to 28.763 MPa for Sample 2 and 20.965 MPa for Sample 3 revealed in Fig. 2.

Table 1: Fibre composition of samples

Sample	Composition by wt%
Sample 1	Sisal fiber=7%, Banana fiber=7%, Bamboo strip=17%.
Sample 2	Sisal fiber=9%, Banana fiber=7%, Bamboo strip=17%.
Sample 3	Sisal fiber=11%, Banana fiber=7%, Bamboo strip=17%.

This observed decline in tensile strength can be attributed to several factors. First, as the sisal fiber content increases, the bonding between the fibers and the matrix (epoxy resin) weakens. The matrix, although chemically bonded to the fibers, cannot transfer the tensile load efficiently when the fiber distribution is uneven. This leads to poor interfacial bonding, which can result in fiber pull-out or matrix cracking under stress. In addition, the alignment of the fibers plays a significant role in the composite's performance. If the fibers are not properly aligned during the manufacturing process, they may not contribute to tensile strength as effectively. Therefore, the reduced tensile strength in the samples with higher sisal fiber content suggests that increased fiber content does not always equate to enhanced material performance, especially when it leads to poor matrix-fiber interaction and fiber misalignment.

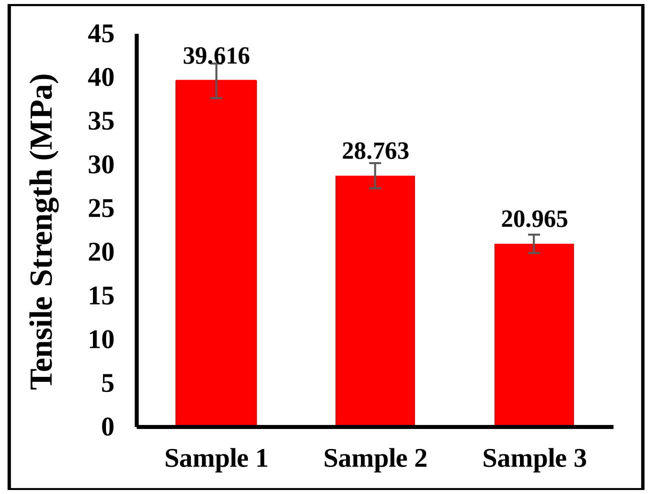

Figure 2: Tensile strength of different composite

Furthermore, the mechanical properties of composite materials are greatly influenced by the arrangement and type of fibers used. Sisal fibers, being natural fibers, are prone to inconsistencies in their properties, such as variations in length, diameter, and surface roughness. These variations may lead to stress concentrations within the composite, which may further contribute to the observed decrease in tensile strength as the fiber content increases. Additionally, the presence of voids or air pockets, which is common in composites with higher fiber content, may further reduce the tensile strength. The results of this tensile test indicate that although the incorporation of sisal fibers does enhance certain properties, it comes at the cost of reducing the material's tensile strength. This suggests that the composition of the composite needs to be optimized in terms of fiber content to achieve a balanced combination of strength and ductility.

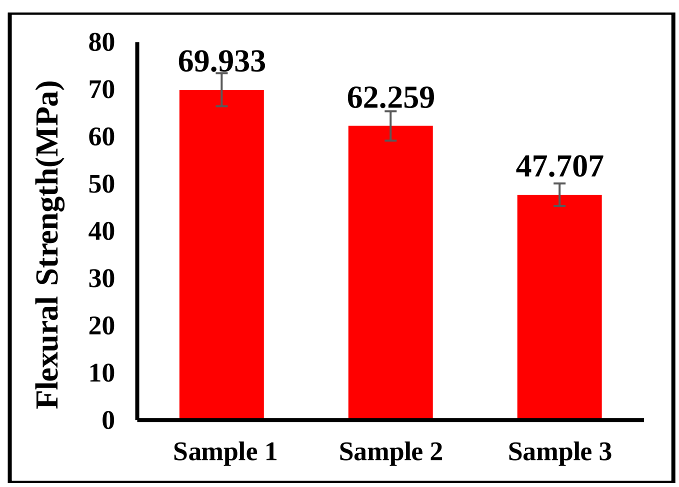

Figure 3: Flexural Strength of different composite

Flexural strength is another important mechanical property that measures a material's ability to withstand bending forces. In this study, flexural testing was conducted to assess the bending resistance of the composite samples with varying sisal fiber content. Similar to the tensile strength results, the flexural strength of the composite decreased as the amount of sisal fiber was increased. Sample 1, which had the least amount of sisal fiber, demonstrated the highest flexural strength at 69.933 MPa. In comparison, Sample 2 had a flexural strength of 62.259 MPa, and Sample 3 had the lowest flexural strength at 47.707 MPa shown in Fig. 3. The decrease in flexural strength with increased sisal fiber content can be attributed to the same factors affecting the tensile strength. As the sisal fibers are incorporated into the composite, they tend to disrupt the uniform distribution of the matrix, resulting in a less rigid structure. The fibers may act as points of weakness within the matrix, leading to localized stress concentrations that can cause bending failure. The matrix, which is typically more rigid than the natural fibers, may not be able to withstand the bending forces when it is reinforced with fibers that do not contribute to the composite's overall stiffness. This results in a reduction in the flexural strength as the fiber content increases. In addition, the interface between the fibers and the matrix plays a significant role in the flexural strength of composite materials. In this case, the poor interfacial bonding between the sisal fibers and the epoxy matrix could reduce the load-bearing capacity of the composite under bending conditions. The absence of good bonding between the matrix and fibers means that the fibers do not contribute effectively to resisting bending forces, leading to a decrease in the overall flexural strength.

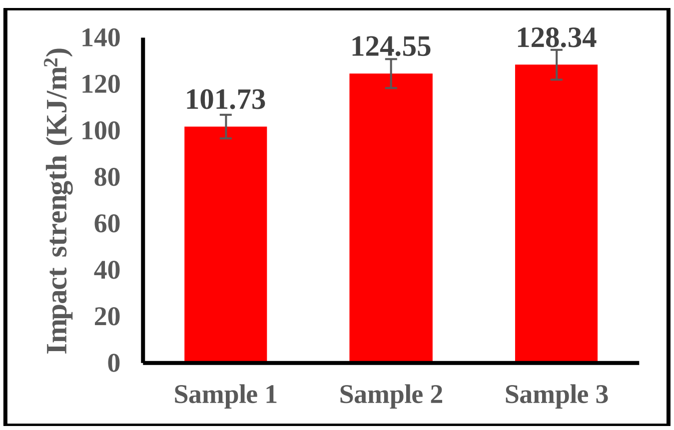

Figure 4: Impact strength of different composite

The flexural testing results highlight the trade-off between the strength of the composite material and its fiber content. While increasing the fiber content can improve certain properties like impact resistance, it can negatively affect the composite's ability to resist bending. This suggests that careful optimization of the fiber-matrix interaction and fiber distribution is essential to achieve the desired flexural properties for specific applications. Impact strength measures a material's ability to absorb energy and resist fracture or deformation when subjected to sudden impacts or shocks. The results from the impact testing conducted in this study reveal an interesting trend. Unlike the tensile and flexural tests, the impact strength of the composite materials increased as the amount of sisal fiber increased. Sample 1, which had the lowest sisal fiber content, exhibited an impact strength of 101.7372 KJ/m². With the increased fiber content in Sample 2, the impact strength rose to 124.5539 KJ/m², and Sample 3, with the highest sisal fiber content, showed the highest impact strength at 128.3414 KJ/m² shown in Fig. 4. This increase in impact strength with higher sisal fiber content suggests that the fibers contribute to the material's toughness. Natural fibers like sisal are known to have good energy-absorbing properties, which can enhance the ability of the composite material to withstand dynamic forces. The presence of sisal fibers helps to dissipate the energy from impacts, reducing the likelihood of catastrophic failure. The fibers likely act as a reinforcing agent, absorbing some of the energy from the impact and preventing immediate fracture of the composite. Additionally, as the sisal fibers are distributed throughout the matrix, they may help to prevent the formation of cracks, thus improving the composite's ability to absorb and resist impact forces.

The increase in impact strength with increased fiber content indicates that while higher sisal fiber content may reduce the composite's tensile and flexural strengths, it can improve its resistance to sudden shocks and impacts. This makes the composite more suitable for applications where impact resistance is crucial, such as in automotive, aerospace, and sports equipment industries. The results of the impact testing demonstrate the potential benefits of using natural fibers like sisal to enhance the toughness and energy absorption capacity of composites.

5. Conclusions

- The tensile strength of the composite materials decreased as the sisal fiber content increased. Sample 1, with the least amount of sisal fiber, achieved the highest tensile strength of 39.616 MPa, while Sample 2 and Sample 3 exhibited tensile strengths of 28.763 MPa and 20.965 MPa, respectively.
- A similar trend was observed in the flexural strength of the composites. Sample 1, with the lowest fiber content, showed the highest flexural strength of 69.933 MPa. As the fiber content increased, the flexural strength decreased to 62.259 MPa for Sample 2 and 47.707 MPa for Sample 3.
- In contrast to the tensile and flexural tests, the impact strength of the composite materials increased as the sisal fiber content increased. Sample 1 exhibited an impact strength of 101.7372 KJ/m², which increased to 124.5539 KJ/m² in Sample 2 and 128.3414 KJ/m² in Sample 3.
- The results indicate a trade-off between strength and toughness. While increasing the fiber content improves

the impact strength, the tensile and flexural strengths decrease significantly. This demonstrates that sisal fiber content positively impacts toughness but reduces the material's ability to resist tensile and bending forces.

- These results suggest that optimizing the sisal fiber content is crucial depending on the desired application. Higher sisal fiber content may be more beneficial for applications where impact resistance is prioritized, while lower fiber content is preferable for applications that require high tensile and flexural strength.

References

[1] D. Chandramohan, T. Sathish, S. Dinesh Kumar, and M. Sudhakar, "Mechanical and thermal properties of jute/aloevera hybrid natural fiber reinforced composites," AIP Conf. Proc., vol. 2283, no. October, 2020, doi: 10.1063/5.0024976.

[2] Husain Mehdi, Arshad Mehmood, Theoretical modelling and experimental investigation on mechanical properties of natural fiber reinforced by epoxy resin matrices, Journal of Materials Science & Surface Engineering, 6(5), 867-871, 2019.

[3] R. P. Chand, Y. P. Ravitej, N. Kumar, Veeracahri, and N. A. Gowda, "Characterization of banana and bagasse fiber reinforced hybrid epoxy composites," AIP Conf. Proc., vol. 2057, no. January, 2019, doi: 10.1063/1.5085624.

[4] S. Nunna, P. R. Chandra, S. Shrivastava, and A. K. Jalan, "A review on mechanical behavior of natural fiber based hybrid composites," J. Reinf. Plast. Compos., vol. 31, no. 11, pp. 759–769, 2012, doi: 10.1177/0731684412444325.

[5] R. Kumar, G. Chandan, and R. Ramamoorthi, "Fabrication and testing of natural fiber hybrid composites," Int. J. Eng. Res., vol. 5, no. 4, pp. 285–288, 2016.

[6] H. Patel, A. Parkhe, and P. K. Shrama, "Mechanical Behaviors of Banana and Sisal Hybrid Composites Reinforced With Epoxy Resin," Int. J. Res. -GRANTHAALAYAH, vol. 4, no. 1, pp. 206–216, 2016, doi: 10.29121/granthaalayah.v4.i1.2016.2866.

[7] R. Siva, T. N. Valarmathi, B. Siddardha, K. Sanjana, and B. Dakshin, Processing and evaluation of mechanical properties of sisal and bamboo chemically treated hybrid composite. Springer Singapore, 2019. doi: 10.1007/978-981-13-2697-4_47.

[8] Husain Mehdi, Rajan Upadhyay, Rohan Mehra, Adit Singhal, Modal Analysis of Composite Beam Reinforced by Aluminium-Synthetic Fibers with and without Multiple Cracks Using ANSYS, International Journal of Mechanical Engineering, 4(2), 70-80, 2014.

[9] Husain Mehdi, Anil Kumar, Arshad Mahmood, Manoj Saini, Experimental Analysis of Mechanical Properties of Composite Material Reinforced by Aluminium-Synthetic Fibers, International Journal of Mechanical Engineering, 2(4), 59-69, 2014.

[10] P. Giri, V. Jayakumar, V. Charan Kumar, and A. Muniappan, "Investigation of mechanical properties of natural fiber composite with & without fiber surface treatments," Int. J. Mech. Prod. Eng. Res. Dev., vol. 8, no. 4, pp. 785–790, 2018, doi: 10.24247/ijmperdaug201881.

[11] C. Xia, S. Q. Shi, L. Cai, and J. Hua, "Property enhancement of kenaf fiber composites by means of vacuum-assisted resin transfer molding (VARTM)," Holzforschung, vol. 69, no. 3, pp. 307–312, 2015, doi: 10.1515/hf-2014-0054.

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