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Research Article

Development and analysis of hybrid sustainable polymer reinforced materials

Md AHASAN[1], Alajingi RAMKUMAR[2], KRKV PRASAD[3,*], Ratnala PRASAD[1], Yarrapragada K S SRAO[1]

[1]*Department of Mechanical Engineering, Aditya University Surampalem, A.P., 533437, India*
[2]*GE VernovaPower Conversion India Private Limited, Chennai, 631604, India*
[3]*Department of Electrical Engineering, Aditya University Surampalem, A.P.-533437, India*

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ABSTRACT

A vast number of researchers are looking for low-cost, lightweight, and highly strong structural materials. In general, light materials are weaker, whereas strong materials are denser. We use composite materials to achieve both high strength and low weight. Next, using impact and ultimate testing machines, the specimens' tensile and impact strengths are determined. Following that, the end output of each composite specimen is analyzed and optimized. Bio-fiber reinforced plastic composites have gained popularity in recent years as people become more environmentally conscious. Composite materials offer several advantages over traditional natural fibers and titanium powder, including lower costs, lightweight construction, environmental friendliness, and recyclable properties. The project's purpose is to make a wide range of composites. Walnut powder combined with 10 grams of Jute, 10 grams of Hemp Fiber, 10 grams of Kenaf, and 10 grams of Jute + Hemp Fiber Hemp + Kenaf Fiber + 10 grams of walnut powder, Jute + Kenaf + 10 grams of walnut powder, Jute + Kenaf + 10 grams of hemp powder powdered walnut due to the interaction of the three fibers. Following the experimentation phase, the manufacturing procedure is carried out with seven examples. Tensile strength, flexural strength, hardness, and impact strength are utilized to calculate the strength of the helmet once it is designed in Catia software and assessed in Ansys. To identify which hybrid material outperforms the other, compare their strengths. The current material performs best in terms of strain, shear stress, von Mises stress, and total deformations. Mechanical and physical testing of manufactured samples is carried out followingAmerican Society for Testing and Materials criteria.

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***Corresponding author.**
*E-mail address: krvprasad219@gmail.com

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INTRODUCTION

The type of polymer does not significantly impact composite strength. This research addresses a previously unknown issue with bamboo fiber composites [1]. The research challenges include demonstrating that adding bamboo fiber powder at a partial size has a significant impact on the behaviour of epoxy composites. Uniform distribution can improve bonding and mechanical properties. Bamboo is a cost-effective, flexible, robust, lightweight material suitable for construction, furniture, packing, and transportation. Epoxy resin is the preferred polymer for bamboo fiber composite research because to its excellent mechanical, chemical, and electrical insulation properties [2,3]. Gigantochleascotechini bamboo fiber powder from Raub, Pahang, Malaysia, aged three to four years, served as the principal reinforcing material and epoxy compound. Bamboo fiber has outstanding mechanical properties, making it a promising solution for standard fibers in composite materials such as carbon and glass. [4]. A class of engineering materials known as composites has generated a lot of interest in a variety of industries, including sports, electronics, biomedicine, aerospace, and automotive. They are made up of two or more components, each of which has unique qualities like strength, stiffness, resistance to environmental deterioration, and reduced thermal expansion. Since it is frequently observed that a single element does not always exhibit all needed qualities, composites are necessary. To get the desired result, however, this can be accomplished by properly combining several materials. [5] . The reinforcement and matrix are the basic elements of composites. The type of composite also differs according to the reinforcement and matrix selected. Owing to their strenth and rigidity composites categersed into any one of these-particle, fiber, metal, ceramic, nano-reinforced, load supported by reinforment and matrix material acts as binders [6]. In the manufacture sector, efforts must be made to meet the demand for new materials as industrial technology advances. Nowadays, industries prefer using other materials which are made of natural fiber-reinforced polymer composite (NFRPC) rather than depending on metals. Glass, carbon, and other silica composites are affordable, ecofriendly and reduces production cost [7]. At high cutting speeds and feed rates that negatively effect on surface quality, mechanical behaviour and poor wear rate with heterogenity of the fibers due to poor bonding between the fibers and polymer matrix can lead to delamination. İn the machining, when excessive heat is produced it weakens the polymer matrix and an uneven chip for motion makes it harder and increases heat buildup. The poor mechanical charecteristics make it difficult to estimate cutting forces because fiber orientation effects cutting behaviour. Even with these challenges studies and developments in machining and tool design are being improved such that it increases product quality and advances the manufactuing composites sectors [8] Right now, there is a trend away from synthetic materials and toward natural fibers. Fillers are now used to make composite materials, which are important for keeping the materials strong. So, mixing organic fibers with additives is a better alternative to synthetic materials for lightweight applications. The study uses Ramie (Boehmeria nivea) fibers as the reinforcement phase and polyester as the matrix material. Then, five composite laminates are made by adding alumina filler with different weight fractions to each sample. This is done to see how the composite affects the ramie fiber (RF) composite's antibacterial conductivity, mechanical properties, and thermal stability. Sample A (120 g RF, 25 g alumina filler, and 120 g epoxy matrix) exhibited the best mechanical properties of all the RF composite samples. It had 25 g of alumina particles and had a tensile strength of 34.89 MPa, a flexural strength of 39.25 MPa, and an impact strength of 0.023 J/mm². The antibacterial results of ramie raw fiber show that ramie cellulose encourages the growth of bacteria, and the energy dispersive investigation shows that the alumina filler is greatly influenced in this RF composite. [9]. Different amounts of nanosilica (0–4% and 5%) have been added to an epoxy matrix to make jute/epoxy/nanosilica (JES) composites. The test demonstrates that adding up to 3% nanosilica filler to the composite enhances its thermal, mechanical, and free vibration characteristics. However, adding more nanosilica has the opposite impact. Adding a little bit of nanosilica to composite materials makes the matrix-fiber interface bind better, but adding more makes the fibers cluster together. Adding nanosilica to the composite material also makes it more stable at high temperatures and slows down its breakdown by 10–140°C. Adding nanosilica to the composite fills in the holes and lowers the damping factor of the JES composite. [10]. Hybrid composites using natural fibers are used in a lot of engineering projects to cut down on the use of synthetic materials. The researchers changed the weight percentages of the 40% banyan and kevlar fiber woven fabric reinforced with 55% aliphatic epoxy polymer and 5% magnesium oxide (MgO) to find out how strong the hybrid composite was. We tested the hybrid composite's strength by putting it through tensile, flexural, compression, impact, and hardness tests. We wanted to see how the weight of the fibers and the order in which they were stacked affected the strength. Adding more kevlar fibers makes all of the mechanical properties of kevlar/banyan fiber-reinforced hybrid composites better, such as tensile strength (226.1MPa) and compressive strength (165.7MPa). The arrangement of the layers in the composite and the weight ratio of the fillers also have an effect on the compressive strength of the hybrid composite. Using surface scanning electron microscopy, we found the most prevalent way that hybrid composites fail. [11].

This research looks at the qualities and usage of cellulose fiber made from pumpkin stems that have been soaked in water. XRD tests showed strong peaks at 13.2° and 16.8° (2θ), which means that the crystalline structure is well-ordered and has a 24.3% crystallinity index. FTIR spectroscopy found peaks at 1430 cm−1 (O-H stretching), 1510 cm−1 (C-H stretching), 1630 cm−1 (C = O stretching), and 1055 cm−1 (C-O-C glycosidic linkage vibrations), which showed that cellulose was present with major functional groups. The SEM image showed a fibrous, porous structure with smooth, round fibers. In the study, pumpkin cellulose fiber stopped the growth of Staphylococcus aureus and Enterococcus faecalis. These discoveries may be useful for wound dressings and lightweight structural and medicinal fabrics.[12]. Concerns regarding sustainability and the environment have prompted scholars to investigate natural alternatives. Natural fiber composites (NFCs) have demonstrated their worldwide potential as an alternative material. This study evaluates the physical, mechanical, and thermal properties of bamboo fiber-reinforced biocomposites using various polymer matrices. Four NFCs (S1, S2, S3, and S4) with 30% bamboo fiber content have been analyzed, utilizing four distinct epoxy matrices. S1 composites demonstrate reduced density (1.02 g/cm^3), elevated bio-content (61.78%), increased tensile modulus (6.98 GPa), flexural strength (154.8 MPa), and flexural modulus (8.42 GPa) in experimental evaluations. S2 composites exhibit the minimal moisture absorption (4.49%), thickness swelling (7.37%), tensile strength (144.76 MPa), storage modulus (8.82 GPa), and glass transition temperature (111.72 °C). S3 composites exhibit the minimal vacancy percentage (1.2%) and hardness (97.6). Nevertheless, S4 composites are the most economical. VIKOR, a multi-criteria decision-making (MCDM) methodology, was employed to determine the optimal material for car interior components from these four options. The process underwent sensitivity analysis. The VIKOR technique preferentially selects S2-type composites compared to the other three options. Hydrophilicity, inadequate interfacial adhesion, and challenging fiber extraction constrain these bio composites.[13]. A sustainable Timoho Fiber (TF) composite is being developed to replace plastic-based synthetic fibers. Organic (egg shell powder - ESP) and inorganic (aluminum powder - AP) fillers are used to evaluate the physical characteristics, mechanical properties, thermal analysis, and morphology of TF-reinforced polyester composites. Considering the volume percentage of TF, organic, and inorganic fillers, the composite was hot pressed. As fiber volume fraction increases, TF-polyester composite density decreases. Densifying supplemental fillers with AP was more successful than ESP. Increased TF volume increased composite tensile and impact strength. Composites with ESP and AP fillers had different mechanical characteristics. Filler increased elasticity modulus, hardness, and thermal resistance but decreased tensile strength. Due to their high thermal conductivity of about 1700°C, ESP and AP fillers provided better thermal resistance than composites without fillers or amorphous ESP fillers. SEM observation confirmed TF-polyester composite mechanical property characterization. [14]. Eichhornia crassipes, popularly known as free-floating water hyacinth, is abundantly found in regional rivers. The fast growth and distribution capacity of this species make it capable of invading the whole water body. Due to the destructive impact of water hyacinth, the government has spent large sums of money on its removal from the water bodies. The paper briefly describes the conversion of water hyacinth into WH fiber during wastewater management operations. WH fiber, together with epoxy resin, creates WH composites. Composite samples reinforced by the fibers of water hyacinth had a tensile strength of 27.06 MPa, flexural strength of 43.51 MPa, and impact strength of 1.25 J. Levels of the water surface in the hyacinth-affected rivers were measured using luggage-based instrumentation system. Studies have been carried out through experimental investigations, which include thermal analysis and mechanical evaluation. The findings reveal that water hyacinth can be successfully used for beneficial purposes in commercial and household use [15]. This research also examines the reinforcement of hybrid ramie/flax natural fibers with epoxy resin as the matrix using compression molding technique. The optimal composition consisted of 40 wt.% ramie/flax natural fiber of a length of 1 cm, resulting in tensile strength of 32.67 MPa, higher than any other combination. Hybrid fiber combinations in the amount of 30–40 wt.% possessed better compatibility with matrix, making it easier for stress transfer and elastic deformation. Flexural strength was enhanced from 43.75 to 52.47 MPa, whereas impact strength was increased from 10.23 to 15.97 kJ/m^2 by increasing the length of fibers to 0.5 cm with 40 wt.% fiber concentration. Fiber reinforcement with 5% NaOH treatment showed significant variation in tensile strength (28.42–32.67 MPa). Compared to the untreated fibers and fibers with 8% NaOH treatment. The combination of natural fibers, such as flax and silk, with artificial fibers, like glass fibers, leads to a different type of mechanical properties of hybrid composites due to varying recyclability and biodegradability [17]. Lannea coromandelica (LC) plant gum is mixed with epoxy resin to produce hybrid Lannea Coromandelica Blender Epoxy (LCE) matrix composite. This is done to replace conventional epoxy resins by improving their biodegradability and ensuring eco-friendly properties [16]. Moreover, hybrid composites were manufactured by reinforcing NaOH-treated and untreated pineapple (PGP), silk (SGS), and flax (FGF) fiber mats with 2%, 4%, and 6% volume of Bentonite nanoclay (BNC) nano filler in each combination of fiber mat hybridization in LCE matrix composite. Prior research mostly looked at the effects of nanofillers on woven textiles or composite materials made of short fibers. The effect of nano-filters on the mechanical characteristics of natural fiber polymer composites has not yet been thoroughly investigated. Comprehensive research on the effects of eco-friendly nanofillers, like nanocellulose and nanosilica particles, on the mechanical, physical, and thermal characteristics of unidirectional long false banana fiber polymer composites (UDLPCs) at various fiber orientations is currently lacking in the public domain.[18]. Because of its durability and low density, fake banana fiber is perfect for applications requiring biocompatibility and light weight. [19,20] . An alternative to coco fiber is coconut coir fiber, which is a material that contains ligneous cellulose. Its ability to raise the economic value of coconut fiber and produce a high-quality product with easily accessible ingredients has so far been well established. [21]. Sofas, car seats, and other items are upholstered with coconut fiber. A useful planting medium is cocopeat. [22]. Coir dust, fine and short bristles, and long fibers are the products of processing coconut fiber. Cocoform, bedsgeotextiles, carpets, and other crafts and household goods can be made from coconut belt fiber. Dust from coconut fibers can be turned into board/hardboard particles, compost, and cocopeat. In the flower industry, cocopeat is utilized as a substitute for real peat. [23]. Aspect ratio's impact on formability and the impact of adding TiB2 to aluminum were thoroughly examined. The instantaneous density coefficient, instantaneous strain rate sensitivity, work hardening exponent, stress ratio parameters, and densification reached were all examined. [24] The response (output) variable was assessed using the load, aspect ratio, and starting preform density as input factors. [25]. Thefindingsshowthat for as-cast Al6061/9%Gr/WC hybrid composites, the WL rises with increasing load, sliding distance, and sliding velocity and falls with increasing WC percentage. Additionally, Coefficient of friction (COF) rises with increasing weight and sliding distance and falls with increasing % of WC and sliding velocity.[26]. P. Car bodywork, energy generation and storage, construction, packaging materials, and even space exploration are just a few of the many areas where polymer-based composites hold great promise. Polymer composites are becoming more and more popular in the automobile sector for their great performance and low weight in fuel-efficient vehicles. Polymers are utilized in a wide range of applications due to their easily modifiable properties, such as their flexibility, chemical and mechanical resistance, and viscoelasticity. Moreover, a wide range of synthetic methods can be used to create polymeric materials with a variety of morphologies and structures, including fibers, films, elastomers, micro- and nanoparticles, branching, linear, and crosslink. [27,28]. This research reviews impact-loaded theoretical and computational modeling methods for natural fiber composites (NFC). NFC behavior under impact loads is important, especially in structural integrity applications. Natural fibers are preferred over synthetic fibers due to their higher specific strength, stiffness, lightweight, and cost-effectiveness, although few review publications discuss their impact loading behavior modeling. The literature on NFC impact behavior concentrated on hybridization, impact testing methodologies, and matrix material. Thus, this literature evaluation emphasizes NFC modeling, which improves composite design and performance. Classical laminated plate and deformation theories are reviewed. Composite material impact mechanics computational models like finite-element analysis (FEA) are also discussed. This study investigates the effect behavior of NFCs, new areas in NFC, and how to improve it, focusing on critical aspects to consider before modeling. The goal is to highlight key theories and computational methods in this subject and raise experts' understanding of ongoing research to guide future studies. [29,30].

In this present study finding the best composite out of the seven possibilities is the aim of this endeavor. The combination of jute, kenaf, and hemp with 10 grams of wall nut shell powder produced the greatest results in the tensile and flexural strength tests, as well as the hardness, impact, and tensile strength tests, after all testing on the specimens were finished.

FABRICATION BY HAND LAYUP PROCESS

Materials

The hand lay-up technique, as shown in Figure 1, is the most straightforward and economical way to manufacture composites. Additionally, relatively minimal infrastructure

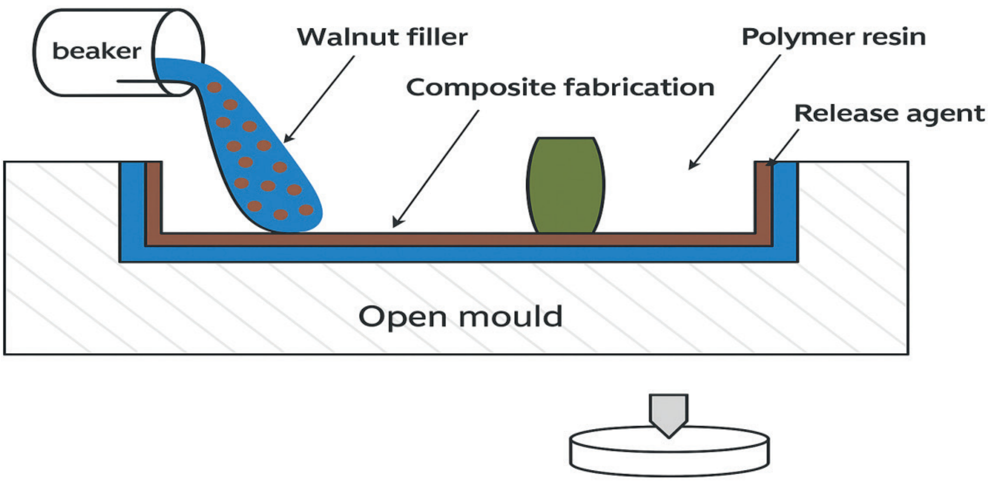

Figure 1. Handlay upprocess.

is needed for this method.The ASTM-D790M-86 standard test technique for the mechanical properties of fiber-resin composites is applied in line with the measurements. Using two-way tape, the mold is prepared on smooth, clear film to the necessary dimensions. While the mold is being produced on the clear film, the two-way tape is left on it.

The long fiber reinforcement is put to the surface of the thin plastic sheet after being cut to the mold's measurements. After carefully combining the recommended hardener (curing agent) with the liquid thermosetting polymer in the proper quantity, the polymer is applied to the transparent surface. The polymer is evenly distributed with a brush. The polymer surface is next covered with a second layer of fiber and then another layer of polymer. After moving the squeezer and carefully compressing the thin plastic sheet to remove any remaining air, this is sealed with it. For a full day, the resultant mold is left to cure at room temperature. Following manufacture, specimens are cut from sheets in compliance with ASTM guidelines.They are made for tensile testing and measure 165 mm in length, 12.5 mm in width, and 4 mm in thickness. They are made for flexural testing and measure 100 mm in length, 25 mm in breadth, and 4 mm in thickness. They are made for impact testing and measure 63.5 mm in length, 12.36 mm in width, and 6 mm in thickness.

Compositions Used

S. No	Composition
1	Kenaf+10 grams wall nut shell powder
2	Hemp+10 grams wall nut shell powder
3	Jute+10 grams wall nut shell powder
4	Kenaf+jute+10 grams wall nut shell powder
5	Jute+hemp+10 grams wall nut shell powder
6	Hemp+kenaf+ 10 grams wall nut shell powder
7	Hemp+kenaf+ jute+ 10 grams wall nut shell powder

Specimens Preparation

All laminates were made by hand layup technique using hemp, kenaf, jute, kenaf+hemp, hemp+jute, jute+kenaf, and jute+kenaf with 10 grams of wall nut shell powder, as illustrated in Figure 2. In this process, 6 specimen sheets of 10 grams of (HY951) hardener are mixed with epoxy (LY556) with 100 grams, which is used as a matrix material in the composite. The specimen's with thickness of 4mm for all impact, tensile, hardness, and flexural tests, and six sheets of fiber matrices are used to achieve this 4mm thickness.

Experimental Setup

The mechanical properties of Natural Fiber Composites (NFCs) were evaluated in accordance with ASTM standards. Four mechanical tests—tensile, flexural, impact,

Figure 2. Complete sequentialprocessfor fabrication (a) taking of epoxy resin b) Mixing of hardener mixture with epoxy resin (c) taking fiber sheet and mixing with walnut powder (d)Pouring on fiber sheet uniformly.

and hardness—were conducted using the following ASTM standards:

Tensile Test – ASTM D638, Flexural Test – ASTM D790, Impact Test – ASTM D256

Hardness Test – ASTM D2240, for each composite variation, four specimens were tested, and the top three values were averaged to determine representative mechanical properties.

Tensile test

Standard: ASTM D638

Specimen Dimensions: 200 mm (length) × 25 mm (width) × 0.5 mm (thickness)

Equipment: Electronic tensometer

Description: Tensile stress was applied by pulling specimens in opposite directions until failure.

Replications: All seven composite variants were tested, with four specimens per variant, totaling 28 specimens.

Data Analysis: The highest three results from each variant were averaged.

Flexural test

Standard: ASTM D790

Specimen Dimensions: 200 mm × 25 mm × 0.5 mm

Description: Specimens were subjected to simultaneous tensile and compressive stressesusing a three-point bending method.

Replications: All seven composite types were tested using four specimens each.

Data Analysis: The three highest values per composite were averaged to determine flexural strength.

Impact test

Standard: ASTM D256

Specimen Dimensions: 55 mm × 13 mm × 0.5 mm

Description: Charpy impact tests were conducted to evaluate the energy absorbed during fracture.

Hardness test

Standard: ASTM D2240

Specimen Dimensions: 30 mm × 30 mm × 0.5 mm

Description: Shore D hardness tests were performed to assess surface resistance to indentation.

RESULTS AND DISCUSSION

The following table lists the characteristics of the fiber-reinforced epoxy hybrid composites made of hemp, kenaf, jute, kenaf+hemp, hemp+jute, jute+kenaf, and jute+kenaf with 10 grams of wall nut shell powder in all compositions. For every test, I have taken every composite. The tests and processing information for these composites were described in the previous chapter. Based on the mechanical test data, a comprehensive analysis was carried out to evaluate the performance of different natural and hybrid fiber composites. Graphical comparisons such as bar charts for tensile strength, flexural strength, impact energy, and hardness were proposed to visualize the variation among composites. The Jute/Hemp/Kenef composite exhibited the highest tensile strength (12750 N), flexural strength (1320 N), impact energy (7.3 J), and hardness (152), indicating its superior overall mechanical performance. A radar chart was also suggested to provide a holistic view of all measured properties across the different composites, highlighting the enhanced balance achieved through hybridization. Correlation analysis between properties such as tensile strength, impact resistance, and hardness can further reveal the interdependence of mechanical behaviors. The mechanical characteristics of man-made fiber reinforced composites are significantly influenced by the composition, fiber type, soil conditions, and air conditions at the time of specimen creation. The chemical composition, fiber type, soil conditions, and unique circumstances at the time of specimen manufacturing all have a significant impact on the mechanical properties of synthetic fiber reinforced composites. Table 1 below lists the characteristics of the fiber-reinforced epoxy hybrid composites made of hemp, kenaf, jute, kenaf+hemp, hemp+jute, jute+kenaf, and jute+kenaf with 10 grams of wall nut shell powder in each composition. For every test, I have chosen a different composite.

Table 1. The tensile, flexural, ImpactandhardnessResultsfordifferentcomposite fiber

S.No	Composite	Tensile test		Flexural Test		Impact	Hardness
		Load (N)	Elongation (mm)	Load (N)	Elongation (mm)	(J)	Number
1	kenef	8250	5.6	1290	8	3	101
2	Jute	5500	6.9	390	8.6	5.2	63
3	Hemp	6520	4.3	830	6.2	6.7	93
4	Jute/Kenef	9390	6.3	870	7.5	4.1	62
5	Hemp/Kenef	10850	6.4	1280	9.1	6.1	128
6	Jute/Hemp	12100	5.9	520	5.3	6.5	127
7	Jute/Hemp/Kenef	12750	4.2	1320	4.1	7.3	152

Here are the findings from a number of characterization tests. Tensile strength, flexural strength, impact strength, and hardness test evaluation are all included in this. has been examined and talked about. Several graphs are plotted and displayed in figures for composites based on the tabulated results.

Tensile Test

Based on the tensile strength finally concluded that hemp/jute/kenaf fiber with 10 grams wall nut shell powder possess high tensile strength [29] as showed in Figure 3 compared to remaining composite.A strong interface between the fibers and the matrix ensures that the composite material can better transfer load as shown in the Figure 4. from the matrix to the fibers for jute, improving the overall tensile strength. The addition of walnut shell powder can create a more compact structure, which can lead to a more compact structure, which generally results in improved strength characteristics, including tensile strength. The powder can also fill voids and gaps between fibers, reducing the likelihood of fiber pull-out or interfacial slip.Hence the stress was high due to the addition of 10 grams of walnut shell powder to hemp, jute, and kenaf fibers can be explained by a number of factors pertaining to the fibers' inherent qualities, the function of the powder, and the composite structure; the powder particles bridge stress-transfer bridges between the fibers and the matrix and fill in gaps in the matrix.

Flexural Test

In this experimental work testing successfully completed, in this investigation the flexural strength of hemp/jute/kenaf fiber with 10 grams wall nut shell powder fibers was high [29] as shown in the Figure 6 in the 7 combinations were fabricated by using hand lay-up method. The

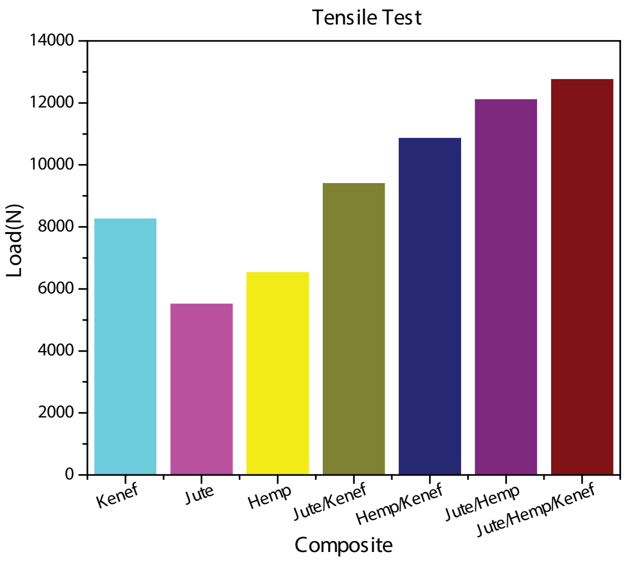

Figure 3. Tensile load for different composite fibers.

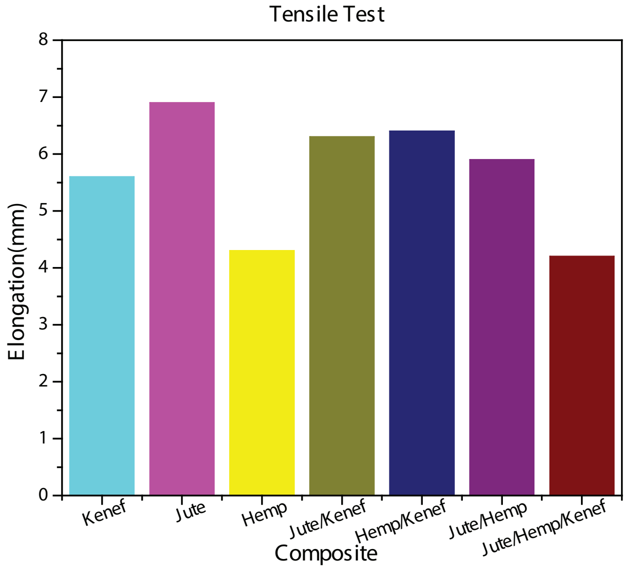

Figure 4. Elongation for different composite fibers.

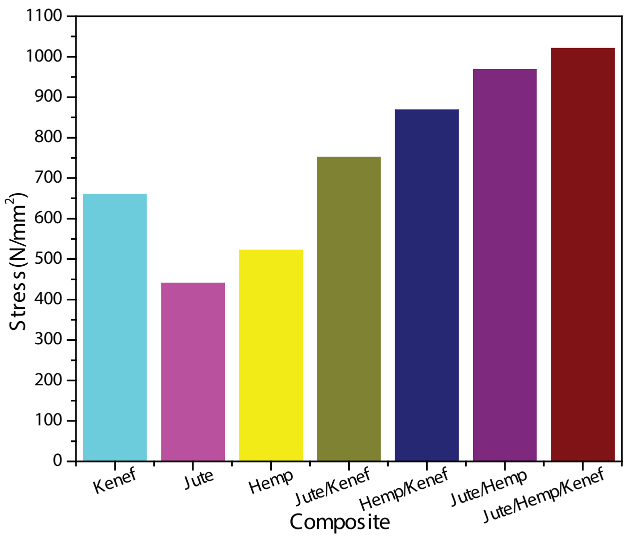

Figure 5. Elongation for different composite fibers.

flexural strength was calculated based the following relation. Due to their high cellulose content and well-aligned microfibril structure, hemp, jute, and kenaf fibers are known for their high tensile and flexural strength. These fibers serve as primary reinforcements in the composite, preventing bending forces, while lignocellulosic powder made from the powdered shell of walnuts acts as a secondary filler, adding stiffness and strength because of its rigidity and compatibility with the natural fibers. Jute/kenefit's lightweight and has good elongation resistance, good mechanical qualities and exceptional toughness as shown in the Figure 7.

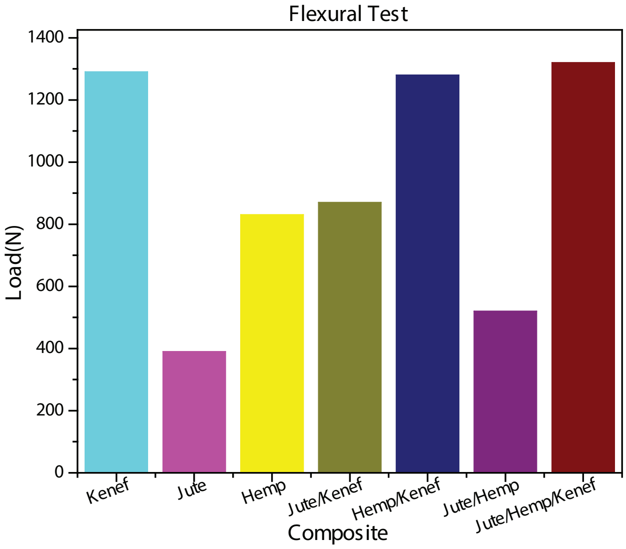

Figure 6. Flexural test Load graph for different composite fibers.

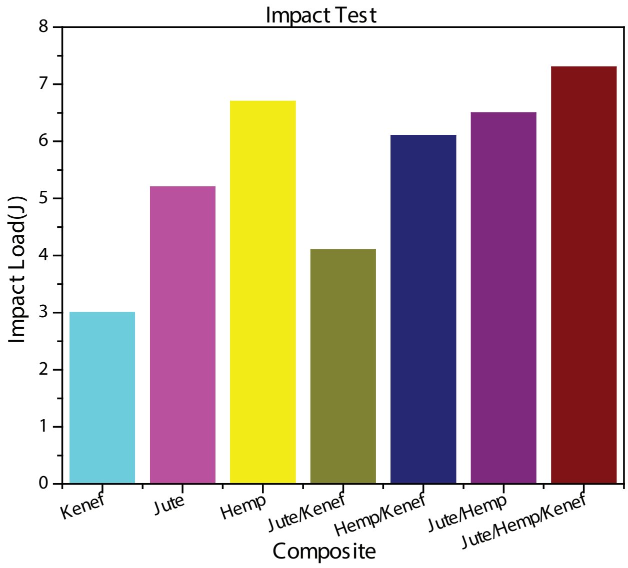

Figure 8. Impact test loadfor different composition fibers.

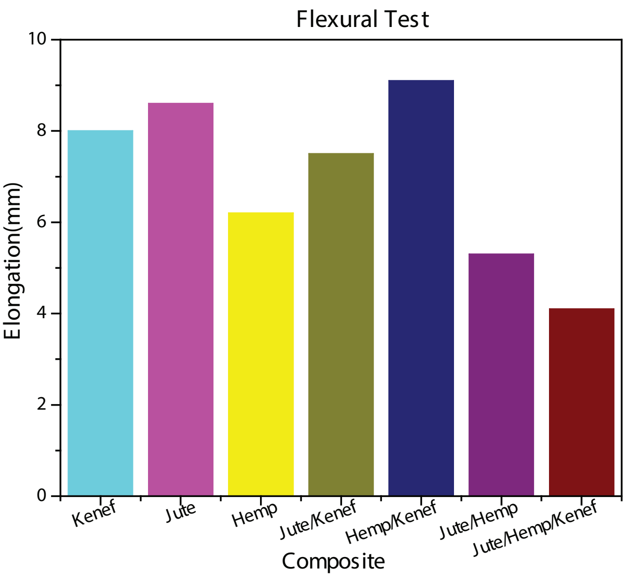

Figure 7. Flexural test elongation for different composite fibers.

Impact Test

Based on the impact strength finally concluded that hemp/jute/kenaf fiber with 10 grams wall nut shell powder possess high (7.3)as shown in Figure 8 compared to remaining composite.The impact strength [29] of a composite is mostly dependent on the interface between the matrix and the natural fibers (hemp, jute, and kenaf). This is due to specimen the fiber can also be powdered, which could boost its strength. Various types of resins can be utilized to determine mechanical qualities such as wear resistance and strength. Hemp fiber has Excellent modulus and tensile strength [29],By filling up gaps and increasing the adherence between the fibers and the surrounding matrix, the powdered walnut shell may strengthen the bonding at this interface. Improved stress transfer during impact results from a stronger matrix-fiber link, which enhances the material's capacity to absorb and disperse impact energy. Strength and impact resistance are probably best balanced at the precise ratio of 10 grams of walnut shell powder to the fibers. While too much powder could damage the composite by interfering with the fiber structure, too little powder might not offer adequate reinforcing to increase impact resistance. The 10-gram quantity might.This combination improves the material's capacity to absorb and disperse impact energy, minimizes fracture propagation, and promotes the fiber-matrix bond, all of which contribute to its exceptional impact resistance.

Hardness Test

Based on the hardness finally concluded that hemp/kenaf fiber with 10 grams wall nut shell powder possess high (152)as shown in the Figure 9 compared to remaining composite.As a filler material, walnut shell powder adds to the composite's hardness by enhancing its general resistance to deterioration, scratches, and indentation. The addition of walnut shell powder to the composite increases the material's hardness by introducing a reasonably strong and rigid component. Toughness, or a material's capacity to absorb energy before breaking, is frequently linked to hardness. Hard and strong materials have superior hardness strength because they can tolerate both abrupt shocks and ongoing stress. The composite may exhibit enhanced resistance to failure under gradual indentation loading by strengthening its resistance to wear, scratching, and

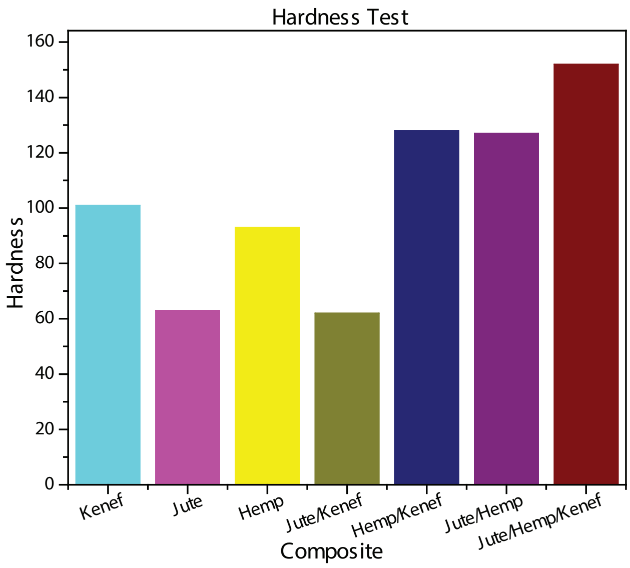

Figure 9. Hardness graph for different composition fibers.

indentation (hardness). Because higher hardness frequently denotes superior overall material integrity, it makes sense to conclude that the hemp/kenaf fiber with 10 grams walnut shell powder composite has high hardness[29]number (152) based on hardness test. The composite's hardness and tensile strength are probably increased by the addition of natural fibers and powdered walnut shell. So that both elements effects on material strength to resist external forces without cracking and deforming, hardness finds the failure under stress and deformation

Therefore, compared to the other composites, hemp/kenefhashigher hardness indicates that it can withstand larger loads.

CONCLUSION

In this research, it aims at determining the best composite from seven combinations of natural fiber materials. The main goal was to find out the mechanical qualities of composites that can be used effectively to produce strong and durable composite materials. The results showed that the best combination for the production of composite materials was a hybrid system that contains fibers made from jute, kenaf, and hemp along with an additional 10 grams of powdered walnut shells. This combination has a unique impact on the composite materials; each fiber plays its role to increase the performance of the final material, which includes enhancing the lightness of the jute fiber, increasing the stiffness of the kenaf fiber, and impact resistance of the hemp fiber, all together helping to distribute the load uniformly and thus reduce flexibility.

This study's purpose is to examine the characteristics of the seven different natural-fiber systems to determine the most suitable combination of fibers. The findings revealed that the ideal combination is a hybrid fiber system made up of jute, kenaf, and hemp fibers along with an additional 10 grams of powdered walnut shell. In this study, jute fiber is chosen due to its lightweight and flexibility, kenaf because of its mechanical strength, while hemp was selected for its stiff and impact-resistant nature. The inclusion of powdered walnut shell into the fiber-matrix interface increases the flexural and tensile strengths of composite materials. Due to being environmentally friendly, this material may have wide uses such as in packaging industry, automotive interior panels, and many others.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

REFERENCES

[1] Raja T, Mohanavel V, Kovuru V, Udhayakumar G, Alnaser IA, Abdo HS, et al. Study of basalt/hemp fibers reinforced B4C nanoparticles influenced hybrid epoxy composite: A novel approach for optical fiber insulation. Opt Quantum Electron 2024;56:427. [CrossRef]

[2] Barman P, Dutta PP, Bardalai M, Dutta PP. Experimental investigation on bamboo fiber reinforced epoxy polymer composite materials developed through two different techniques. Proc Inst Mech Eng C J Mech Eng Sci 2024;238:2185-2204. [CrossRef]

[3] Raja T, Devarajan Y. Analysis of the properties of a novel natural fibre extracted from pumpkin plant stalks: A sustainable alternative for lightweight applications. Mater Lett 2024;357:135748. [CrossRef]

[4] Ramesh V, Karthik K, Cep R, Elangovan M. Influence of stacking sequence on mechanical properties of basalt/ramie biodegradable hybrid polymer composites. Polymers (Basel) 2023;15:985. [CrossRef]
[5] Amjad A, AnjangAb Rahman A, Awais H, Zainol Abidin MS, Khan J. A review investigating the influence of nanofiller addition on the mechanical, thermal and water absorption properties of cellulosic fibre reinforced polymer composite. J Ind Text 2022;51:65S-100S. [CrossRef]
[6] Mishra T, Mandal P, Rout AK, Sahoo D. A state-of-the-art review on potential applications of natural fiber-reinforced polymer composite filled with inorganic nanoparticle. Compos Part C Open Access 2022;9:100298. [CrossRef]
[7] Khalid MY, Rashid AA, Arif ZU, Ahmed W, Arshad H, Zaidi AA. Natural fiber reinforced composites: Sustainable materials for emerging applications. Results Eng 2021;11:100263. [CrossRef]
[8] Gani Akhyar A, Ibrahim M, Ulmi F, Farhan A. The influence of different fiber sizes on the flexural strength of natural fiber-reinforced polymer composites. Results Mater 2024;21:100534. [CrossRef]
[9] Raja T, Vinayagam M, Venkataramanan A, Mohankumar A, Chinnathambi A, Alharbi SA, et al. Effect of nano alumina particles on Boehmeria nivea fiber reinforced polyester green composite: Biological, elemental and mechanical analysis. Opt Quantum Electron 2024;56:538. [CrossRef]
[10] Singh S, Hirwani C. Effect of nano filler on the mechanical, thermal, and free vibration behavior of a jute polymer composite. Russ Phys J 2024;67:55-61. [CrossRef]
[11] Raja T, Raja KV, Reddy MI, Al Obaid S, Alharbi SA, Kalam MA. Studies on mechanical and morphological behaviors of banyan/kevlar fibers reinforced MgO particulates hybrid aliphatic epoxy composite. Int J Interact Des Manuf 2023:1-8. [CrossRef]
[12] Raja T, Devarajan Y. Analysis of the properties of a novel natural fibre extracted from pumpkin plant stalks: A sustainable alternative for lightweight applications. Mater Lett 2024;357:135748. [CrossRef]
[13] Saha A, Kulkarni ND, Kumari P. Development of Bambusa tulda-reinforced different biopolymer matrix green composites and MCDM-based sustainable material selection for automobile applications. Environ Dev Sustain 2023:1-37. [CrossRef]
[14] Gapsari F, Purnowidodo A, Setyarini PH, Hidayatullah S, Suteja, Izzuddin H, et al. Properties of organic and inorganic filler hybridization on Timoho fiber reinforced polyester polymer composites. Polym Compos 2022;43:1147-1156. [CrossRef]
[15] Arivendan A, Jebas Thangiah WJ, Das R, Ahamad D, Chithra GK. Effect of water hyacinth (Eichhornia crassipes) plant into water bodies and its composite materials for commercial applications. Proc Inst Mech Eng C J Mech Eng Sci 2023;237:5381-5390. [CrossRef]
[16] Sumesh K, Ajithram A, Palanisamy S, Kavimani V. Mechanical properties of ramie/flax hybrid natural fiber composites under different conditions. Biomass Convers Biorefin 2023:1-12. [CrossRef]
[17] Prabhu P, Karthikeyan B, Vannan RRRM, Balaji A. Dynamic mechanical analysis of silk/glass, pineapple/glass and flax/glass reinforced hybrid nanocomposites. J Material Res Technol 2021;15:2484-2496. [CrossRef]
[18] Kalifa MA, Habtu NG, Jembere AL, Genet MB. Characterization and evaluation of torrefied sugarcane bagasse to improve the fuel properties. Curr Res Green Sustain Chem 2024;8:100395. [CrossRef]
[19] Gashawtena E, Kidane A, Sirahbizu B. Comparison of the tensile strength of single natural fibers. Cellulose 2024:1-16. [CrossRef]
[20] Dejene BK, Geletaw TM. A review on false banana (Ensete ventricosum) fiber reinforced green composite and its applications. J Nat Fibers 2023;20:2244163. [CrossRef]
[21] Hasan KM, Horvath PG, Bak M, Alpar T. A state-of-the-art review on coir fiber-reinforced biocomposites. RSC Adv 2021. [CrossRef]
[22] Mishra L, Basu G. Coconut fibre: Its structure, properties and applications. In: Handbook of natural fibres. Woodhead Publishing; 2020. p. 231-255. [CrossRef]
[23] Reddy N. Processing and properties of coconuts. In: Sustainable applications of coir and other coconut by-products. Springer; 2019. [CrossRef]
[24] Ahasan M, Davidson MJ. Experimental investigations on the densification and deformation behaviour of Al-TiB2 composite preforms. Mater Manuf Process 2015;30:1. [CrossRef]
[25] Ahasan M, Chandramouli DS. A prediction model based on simulation (FEA) and response surface methodology (RSM) for sintered Al-TiB2 preforms. 2024. [CrossRef]
[26] Rao TB, Ponugoti GR. Response surface methodology based modelling of friction-wear behaviour of Al6061/9% Gr/WC MMCs and its optimization using fuzzy GRA. Trans Indian Inst Met 2020;74:159. [CrossRef]
[27] Yao P, Zhu B, Zhai H, Liao X, Zhu Y, Xu W, et al. Review on polymer-based composite electrolytes for lithium batteries. Front Chem 2019;7. [CrossRef]
[28] Haque MS, Nomani M, Akter A, Ovi IA. Synergistic effect of Mg addition on the enhancement of mechanical properties and corrosion behavior of aluminum alloys. Heliyon 2024. [CrossRef]
[29] Mohammed K, Zulkifli R, Tahir MFM, Gaaz TS. A study of mechanical properties and performance of bamboo fiber/polymer composites. Results Eng 2024;23:102396. [CrossRef]
[30] Mulenga TK, Rangappa SM, Siengchin S. Impact behavior of natural fiber composites: A comprehensive review on theoretical and computational modelling. Next Mater 2025;8:100849. [CrossRef]