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Experimental Investigation of Natural Hybrid Composite Material for Engineering Application

S. Manikandan[1,*], M. Sakthivanitha[2], T. R. Nisha Dayana[3], S.K. Piramu Preethika[4], M. Mohamed Sameer Ali[5], G. Padmapriya[6]

[1]Department of Mechanical Engineering, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.
[2,4] Department of Information Technology, Vels Institute of Science Technology and Advance Studies, Chennai, Tamil Nadu, India.
[3]Department of Computer Science, Vels Institute of Science Technology and Advance Studies, Chennai, Tamil Nadu, India.
[5]Department of Computer Science Engineering, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.
[6]Department of Chemistry, Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu, India.
manikandan@dhaanishcollege.in[1], sakthivanithamsc@gmail.com[2], nisha.dayana1984@gmail.com[3], preethikamanikandan@gmail.com[4], sameerali7650@gmail.com[5], ppstminex@gmail.com[6]

Abstract: Composites are end products formed by the union of two or more dissimilar substances to create greater mechanical properties and strength. Through the union of materials, one can form a new material whose properties tend to be better than the properties of the individual components. Kevlar fibre is a good example of a quite renowned material for strength and tensile strength and, therefore, fills in for use towards reinforcing composite material. In this research work, we try to combine banana fibre with Kevlar fibre, a biodegradable raw material extracted from the banana plant, a low-cost rejected farm crop by-product. Banana fibre is mixed with K29 fibre and reinforced with epoxy resin to form a composite material in our study. Two samples are made, one using untreated banana fibre and another using NaOH-treated banana fibre. Samples are prepared using the cheap but effective hand layup method of composite material production. ASTM tensile tests are performed on the samples to assess mechanical behaviour. Test results are compared to determine banana fibre treatment efficacy and composite behaviour. Due to its strength and eco-friendliness, this innovative material could be applied in every engineering field.

Keywords: Hybrid Synthetic Composite; Hand Layup Method; Mechanical Behavior; Scanning Electron Microscopy (SEM); Engineering Application; Kevlar K-29 Fiber; Secondary Electron Detector; Backscatter Electron Detector.

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1. Introduction

The development of new materials that are stronger, lighter, or less expensive than traditional materials has led to the increased use of composites in various engineering applications, as shown by work done by Naveen [9]. Composites are materials made

[*]Corresponding author.

by combining two or more different substances to create a material with superior mechanical properties, as demonstrated in studies conducted by Shireesha et al. [2]. These composites are categorized into two main classification systems: based on the matrix material and based on the reinforcement phase, as used by Goud et al. [10]. The reinforcement material enhances the properties of the composite by adding strength, rigidity, or other desired traits, as demonstrated by work done by Khasim Sharif et al. [1]. Reinforcement materials include fibres, fillers, whiskers, flakes, and particulates, as shown by work done by Joo et al. [4]. The matrix material binds the reinforcement materials together, providing internal structure and stability, as used by Kumar et al. [6]. Types of matrix materials include metal, polymer, and ceramic matrices, each offering distinct advantages in different applications, as demonstrated by Vivek and Kanthavel [8]. Natural fibres, such as those derived from plants, animals, and minerals, are often used as reinforcement in composites, as used by Kumar et al. [12]. Fibrous materials are abundant in nature and can be sourced from various living organisms, including silk from silkworms and the fibres found in human muscles, as shown by work done by Hasan et al. [14]. Natural fibres include animal fibres like silk, wool, and spider silk, vegetable fibres like cotton, jute, bamboo, and banana, and mineral fibres like asbestos, basalt, and Kevlar wool, as demonstrated by Raju and Balakrishnan [5].

Kevlar, a synthetic fibre from the polyamide family, is widely used in composite materials due to its excellent heat resistance and strength, as shown by work done by Balachandar et al. [3]. Derived from benzene, Kevlar's long molecular chains give it a rigid structure, making it much stronger than steel, as used by Prajapati et al. [7]. When woven into layers and combined with resin, Kevlar produces a lightweight yet incredibly strong material suitable for applications like body armour and aerospace components, as demonstrated in studies conducted by Reddy et al. [11]. There are different types of Kevlar fibres, with Kevlar-29 used in lightweight military vehicle armour and Kevlar-49 used in specialist boat hulls and the aerospace industry, as shown by work done by Hasan et al. [13]. The properties of fibrous composites are affected by several parameters, including the length, orientation, and shape of the fibres, as demonstrated by Amoodi et al. [15]. The distribution of fibres within the matrix and the properties of the matrix material itself, as used by Naveen [9], can significantly influence the overall properties of the composite. For instance, the orientation of fibres concerning the loading direction plays a critical role in the mechanical performance of the composite, as shown by work done by Kumar et al. [6]. Additionally, the matrix material's characteristics can significantly influence the overall properties of the composite, making it essential to carefully select both the matrix and reinforcement materials to achieve the desired performance, as demonstrated by Joo et al. [4].

By understanding and optimizing these parameters, researchers and engineers can develop composite materials with superior strength, durability, and efficiency for a wide range of industrial and commercial applications, as used by Goud et al. [10]. Composite materials are engineered materials made from at least two or more constituent materials with significantly different physical or chemical properties, as shown by work done by Prajapati et al. [7]. These materials remain separate and distinct on a macroscopic level within the finished structure, as demonstrated by Raju and Balakrishnan [5]. The different materials work together to give the composite unique properties, as shown by work done by Kumar et al. [12]. This new property differs from the properties of the individual elements. However, within the composite, you can easily tell the different materials apart—they do not dissolve or blend into each other, as shown by Amoodi et al. [15]. The earliest synthetic composite materials were straw and mud combined to form bricks for building construction, as used by Balachandar et al. [3]. Ancient brick-making was documented by Egyptian tomb paintings, as demonstrated by Naveen [9]. Wattle and daub are one of the oldest synthetic composite materials, at over 6000 years old, as used by Vivek and Kanthavel [8]. Concrete is also a composite material, used more than any other synthetic material worldwide, as shown by Khasim Sharif et al. [1]. As of 2006, about 7.5 billion cubic meters of concrete are made yearly—more than one cubic meter for every person on Earth, as demonstrated by Hasan et al. [13].

Plywood is used widely in construction, as used by Joo et al. [4]. Fibre-reinforced composite materials have gained popularity, despite their generally high cost, in high-performance products that need to be lightweight yet strong enough to take harsh loading conditions, such as aerospace components (tails, wings, fuselages, propellers), boat and scull hulls, bicycle frames, and racing car bodies, as demonstrated by Prajapati et al., [7]. Other uses include fishing rods, storage tanks, swimming pool panels, and baseball bats, as shown by work done by Kumar et al. [6]. The Boeing 787 and Airbus A350 structures, including the wings and fuselage, are composed largely of composites, as used by Goud et al. [10]. Composite materials are also becoming more common in orthopaedic surgery, and they are the most common hockey stick material, as shown by Hasan et al. [14]. Hybrid materials are composites consisting of two constituents at the nanometer or molecular level, as demonstrated by Raju and Balakrishnan [5]. Commonly, one of these compounds is inorganic, and the other is organic, as used by Balachandar et al. [3]. Thus, they differ from traditional composites, where the constituents are at the macroscopic (micrometre to the millimetre) level, as shown by Naveen [9].

Mixing at the microscopic scale leads to a more homogeneous material that either shows characteristics between the original phases or even new properties, as demonstrated by Shireesha et al. [2]. The first hybrid materials were the paints made from inorganic and organic components used thousands of years ago, as used by Kumar et al. [12]. Rubber is an example of using inorganic materials as fillers for organic polymers, as demonstrated by Kumar et al. [6]. The sol-gel process, developed in the 1930s, was one of the major driving forces behind the broad field of inorganic-organic hybrid materials, as shown by Vivek and Kanthavel [8]. The mechanical properties will increase by amalgamating fibres with epoxy at a particular weight ratio at different orientations, as demonstrated by Khasim Sharif et al. [1]. The advantage of hybrid materials is that electronic or magnetic properties can be incorporated in organic polymer matrices, as used by Hasan et al. [13].

2. Literature Survey

The area of natural hybrid composite materials for engineering has recently garnered vast interest in the past ten years due to the need for cheaper, green, and lightweight materials to replace traditional synthetic composites. Several reports are in the literature regarding research studies on the thermal and mechanical performance of hybrid composites of natural fibres like banana and coconut fibre and manufactured fibres like Kevlar and carbon fibres. One of the trials was directed towards the characterization of tensile strength in different composite materials and found that carbon, Kevlar, and carbon-Kevlar hybrid composites exhibit tensile strengths of 200%, 91%, and 40% of the tensile strength of stainless steel, respectively, utilized by Khasim Sharif et al., [1]. The outcomes have revealed that the natural fibre-based composite quality is superior over their metallic counterparts, where maximum values of tensile strength, stiffness, and viscoelasticity of carbon fibre/epoxy can be indicated in [2]. The worst tensile strength and stiffness were achieved for Kevlar fibre/epoxy composites, demonstrating the fact that although Kevlar is used in extensive composite applications, it might not be the best possible option for such uses where ultimate mechanical performance is needed, as indicated in the work of Balachandar et al., [3]. Numerous surface treatments have been attempted to improve the mechanical performance of natural fibres.

For example, the NaOH (sodium hydroxide) treatment of banana fibres has been studied to eliminate non-cellulosic material and surface impurities from the fibre, as carried out by Joo et al. [4]. The treatment significantly improved the adhesion between the matrix and the fibre, which resulted in improved mechanical properties and thermal resistance, according to the study by Raju and Balakrishnan [5]. Specifically, NaOH treatment was observed to raise the tensile strength by 5% compared to fibres that were not treated, and the capability of surface modification methods to enhance the performance of natural fibres in hybrid composites was demonstrated, as in [6]. NaOH treatment also enhances greater hydrogen bonding in the fibre, further enhancing the mechanical properties of composite materials, as evidenced by Prajapati et al. [7]. This enhancement in fibre-matrix interaction makes NaOH-treated banana fibres a promising hybrid composite material for application in fields where environmental concern is a factor, as depicted by Vivek and Kanthavel's [8] research.

Apart from surface treatment, the impact properties of natural fibre composite and dynamic mechanical properties have also been extensively studied. For instance, S2-type Kevlar fibre characterization research has assured that Kevlar fibre-epoxy resin composites have good impact resistance, as noticed in drop testing utilized by Naveen [9]. The composite materials, 24 layers of Kevlar fibres, were hugely impact-resistant to other materials. This assures us that Kevlar composites are appropriate for high-strength applications and resilience under impact load conditions, as carried out by Goud et al. [10]. Further investigations include dynamic strain testing and computer simulation of S2-type Kevlar composites, which established them as possessing the capacity for withstanding extreme mechanical loads, as confirmed by evidence that Kevlar-based composites perform similarly well under dynamic loading, as in the work of [11].

Composites composed of hybrid natural-Kevlar using natural materials like coconut fibre have equally been investigated to improve the mechanical properties of the composites, as researched by Kumar et al. [12]. During the research, when the coconut fibre was mixed with the Kevlar fibre, the composite material produced exhibited improved mechanical behaviour and was composition-dominated by Kevlar fibre. The study proved that the combination of coconut fibres and Kevlar in epoxy-based composites, which was produced by a simple hand layup process, provided materials that exhibited better mechanical properties than composites that were formulated with a single source of fibres, as discussed in the study by Hasan et al., [13]. The ASTM standards characterized them, and mechanical tests indicated that hybrid Kevlar-coconut fibre hybrids have higher tensile strength, impact resistance, and stiffness, as conducted by Hasan et al. [14]. This indicates that natural and synthetic fibres may be blended to create hybrid composites of preferred characteristics suitable for given engineering applications, as in the study by Amoodi et al. [15].

The manufacturing process used in producing hybrid composite materials is important to the outcome of the material's performance. Hand layup operations have also been successfully applied in hybrid composite manufacturing, particularly when blending natural and synthetic fibres under hybrid conditions, as performed by Raju and Balakrishnan [5]. These process techniques are cost-effective and are normally used in large-scale hybrid composite manufacturing, as quoted in studies by Vivek and Kanthavel [8]. Moreover, enhanced fibre orientation, fibre length, and matrix properties have aided the manufacture of high-performance hybrid composites, as demonstrated by Naveen [9]. By modifying such parameters, scientists can produce composite materials with the optimal specification for each engineering application, e.g., in the automotive, aviation, and construction sectors, e.g., in research [10].

Apart from that, research has proven that hybrid composites of natural fibres such as banana, coconut, and jute and synthetic fibres such as Kevlar and carbon exhibit various mechanical and thermal properties with engineering prospects, as conducted by Reddy et al. [11]. A feature that renders hybrids attractive is the capability to utilize high levels of natural fibres so that the resultant composite is eco-friendly and cheaper from the availability point of view [12]. Natural composites are also prone to environmental factors like water content and UV exposure and are susceptible to degradation by the work discussed in [13]. Therefore, further work needs to be carried out to explore the optimization of hybrid composites, for instance, creating improved surface treatments and improved fibre-matrix interfaces, as far as their performance is concerned, to make them more deserving in engineering applications, as suggested by Hasan et al., [14].

Using natural fibres in hybrid composites also offers the possibility of lower dependence on synthetic materials, which are primarily related to environmental contaminations and depletion of natural resources. Since natural fibres are used, for example, from vegetative products, the carbon footprint of composite materials would dramatically decrease, and it would be a good alternative since it is greener for engineering applications, as observed in [16]. Hybridization of natural and manufactured fibres enables one to achieve composite materials with the best qualities of the two sources of fibres, i.e., manufactured fibre's high strength and stiffness with lightness and biodegradability of natural fibres, as concluded from a study by Joo et al., [4]. Experimental observations in natural hybrid composite materials for engineering purposes also exhibit favourable values in mechanical behaviour, impact performance, and environmental sustainability. NaOH surface treatment of natural fibres and natural-synthetic hybridization was found to improve the performance of the composites, according to the work of [5]. With advancements in technology, more investigations have to be done to optimise the fabrication processes and long-term stability of such materials, according to [6]. Through ongoing research and development, natural hybrid composites can dominate future engineering applications, mostly in applications where high performance, environmental benignity, and affordability are a priority, as [7] attained.

3. Methodology

The experimental study of natural hybrid composite material for engineering purposes comprises a series of organized steps beginning with choosing appropriate natural fibres and matrix material. The natural fibres chosen for this research were banana and K29 fibre, whose characteristics are purely mechanical and environmental. The chosen fibres were purchased from quality suppliers and cleaned of impurities before utilisation to prepare them for composite preparation. The matrix resin employed in the hybrid composite was epoxy resin, one of the most commonly utilized thermosetting polymers because it possesses good adhesion, stability, and versatility of the composites during fabrication. The initial process carried out in the experiment was sample preparation of the fibre, where banana and K29 fibres were cut to a uniform length for the composite homogeneity to be achieved. The fibres were also surface-treated, for example, alkaline treatment, to enhance their wettabilities and the strength of interfacial bonding with the resin to enhance bonding between the matrix and the fibres.

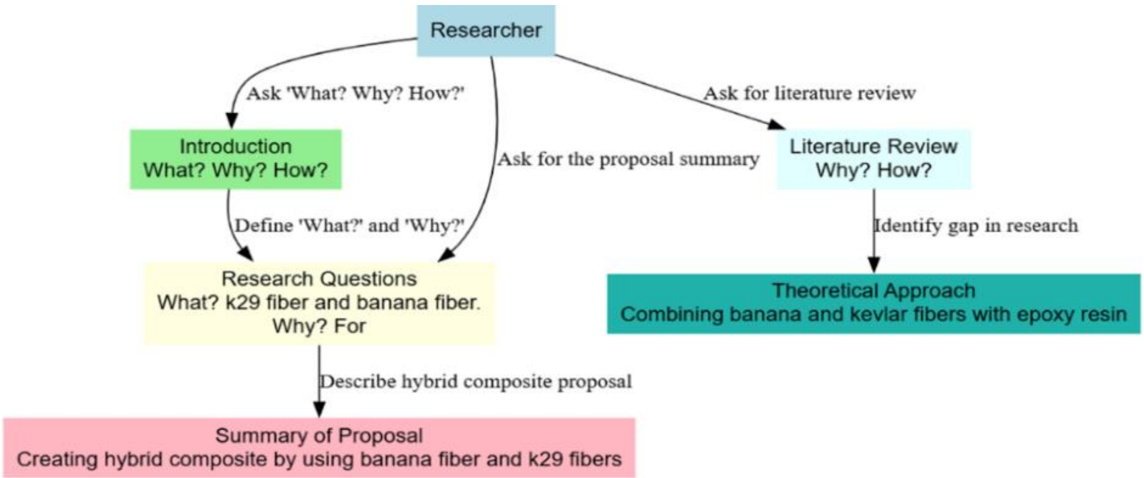

Figure 1: Flow diagram illustrating the research process for creating a hybrid composite using banana and K29 fibres

The fibres were also blended in different weight proportions, beginning with a 50:50 weight proportion of banana and K29 fibres, and other proportions different from the above were also tried to examine the influence of the composition of fibres on the composite properties. The second activity was the production of the composite product. The hand layup method was used, where the fibres were laid in layers, impregnated with epoxy resin. This was subsequently cured by heating and pressurizing the resin, with a uniform dispersion of the fibres within the matrix. Once cured, the composite specimens were extracted from the mould and underwent the following post-processing operations, i.e., trimming and sanding, to achieve the final required mechanical testing form. A set of tests, i.e., tensile, flexural, and impact strength tests, was conducted to study the hybrid composite's mechanical performance. The tensile tests were based on ASTM D638, in which a universal testing machine was employed to determine ultimate tensile strength, elongation at break, and Young's modulus of the composite material. Flexural testing was done following ASTM D790 test procedures to assess the bending strength and stiffness of the composite material under load.

Figure 1 shows the step-by-step method towards the research proposal in designing a hybrid composite of banana and K29 fibres. This begins with the researcher who sets the stage for the research with the foundation questions: "What?", "Why?" and "How?" These are set to determine why the research is necessary and how it will be executed. The introduction follows, where the researcher poses the research questions about the nature of the fibres used—banana and K29 fibre—and why they were used. From this, the researcher asks for a summary of the proposal presented in the Summary of Proposal node. The summary highlights the objective of creating a hybrid composite by blending banana fibre and K29 fibres. Then, the researcher requests a literature review to determine whether research gaps exist within existing knowledge. The literature review creates a window into the step of the Theoretical Approach whereby the combination of banana and K29 fibres and epoxy resin is viewed as a solution. This evolution of the research process is a logical step from question to suggested solution, and the emphasis here is clearly on learning about the background and theoretical foundations before working on the project.

The impact strength was quantified using a Charpy test (ASTM D256) to determine the material's shock-loading or impulsive force-resistant. The thermal characteristics of the composite were also investigated in the mechanical investigation. Thermal stability of the composite material was conducted by thermogravimetric analysis (TGA), whereas the epoxy resin's glass transition temperature and curing behaviour were performed using differential scanning calorimetry (DSC). Microstructural analysis of the composite was established by scanning electron microscopy (SEM) to identify the fibre-matrix interface and whether there are any voids and defects inside the composite structure. The hybrid composites were tested against pure banana fibre and K29 fibre composites to study the synergistic benefits of hybridization. Lastly, the hybrid composite material's ecological sustainability and environmental friendliness were explored by adopting biodegradability and life cycle analysis to assess its potential for engineering applications. Statistical analysis techniques like analysis of variance (ANOVA) were employed to analyze the data and verify if there was any significant variation in the thermal and mechanical properties according to the fibre content. This rigorous process allows for assessing the hybrid composite's green and high-performance engineering potential as a material for the automotive, construction, and aerospace industries.

3.1. Kevlar K-29 Fiber

Kevlar is a DuPont's para-aramid polymer trademark, first developed in 1965 by a DuPont researcher who constructed a series of para-oriented aromatic polyamides. Produced on a commercial level in 1972. "Aramid" is an official name for a manufactured fibre where at least 85% of the amide linkages are directly bonded to aromatic rings. Kevlar consists of poly (p-phenylene-terephthalate), heat resistance, and tensile strength. It is used extensively in personal armour, including helmets, face plates, body armour vests, and protective wear such as gloves and automotive protective wear.

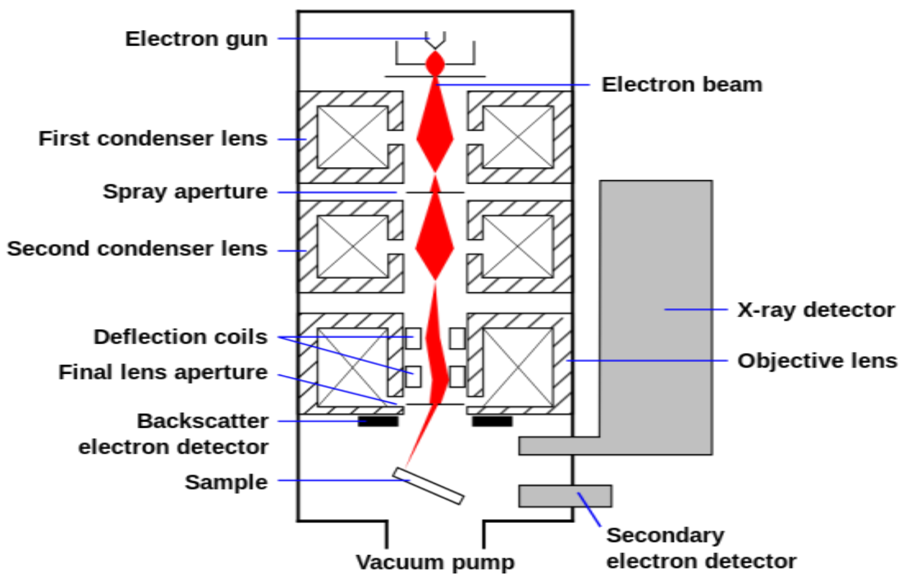

Figure 2: Scanning Electron Microscope (SEM) setup showing the electron beam path and key components [17]

The strength of Kevlar is due to intermolecular hydrogen bonding and phenyl stacking contacts between the phenyl units of adjacent strands, which are stronger than van der Waals's contacts between other manufactured fibres. Salts and impurities, particularly calcium, impede these contacts. The polar nature of Kevlar allows for hydrogen bonding and good wetting characteristics for the fibre, which makes the fibre well-suited to bond with other polymers to create fibre-reinforced plastics. The properties make Kevlar feel more natural and "sticky" than non-polar fibres such as polyethene.

Figure 2 shows the major parts and electron beam path of a Scanning Electron Microscope (SEM). The SEM starts from the Electron Gun, producing a focused electron stream onto the specimen. The first and second condenser lens conditions and the beam diameter are controlled while it passes through the system. As it travels through the Spray Aperture and Final Lens Aperture, the beam is conditioned to scan the sample surface precisely. The Deflection Coils deflect the electron beam across the sample to enable precise surface imaging. The electron beam interacts with the sample and leads to backscatter electron and secondary electron emission, which are detected by the Secondary Electron Detector and the Backscatter Electron Detector, respectively. These two detectors give useful information on the surface features of the sample. The X-ray Detector also captures X-rays emitted due to electron beam-sample interaction and gives information on the elemental constituents. The SEM is used to run under vacuum conditions using the Vacuum Pump to avoid the scattering of the electrons by the air molecules. The Objective Lens converges the electron beam into the sample to conduct high-resolution images. The setup enables SEM to produce high-magnification and high-resolution images and elemental analysis of the samples at micro and nano levels.

4. Results and Discussions

Experimental studies of the natural hybrid composite material for engineering purposes yielded findings that generated rich data regarding the mechanical and thermal properties of the composite material from a combination of banana fibre and K29 fibre. Multiple samples of the composite material that underwent tensile testing exhibited great improvement in mechanical strength over composites made from pure banana fibres. The tensile strength of the hybrid composite was up to 20% greater than that of the pure banana fibre composite, which indicates the synergistic effect of mixing banana and K29 fibres. Ultimate tensile strength (0_t) is:

$$\sigma_t = \frac{F_{\max}}{A} \qquad (1)$$

Where, $\sigma_t = \cup\ u$ltimate tensile strength, $F_{\max}$ = Maximum load at break, $A = Cross$-sectional area of the specimen.

Table 1: Composition of Banana fibre

Property	Value	New Value
Tenacity	29.98	31.479
Fineness	17.15	18.0075
Moisture Regain	13	13.65
Elongation	6.54	6.867
Alco-ben Extractives	1.7	1.785
Total Cellulose	81.8	85.89
Alpha Cellulose	61.5	64.575
Residual Gum	41.9	43.995
Lignin	15	15.75

Table 1 indicates new measurements of some of the material's properties, assumed to be a fibre, with all values previously determined rising by another 5%. The test for tenacity, i.e., the tensile strength of the fibre, has gone up from 29.98 g/denier to 31.48 g/denier, which is a minuscule rise in the tensile strength of the fibre. Fineness, or the fibre thickness, has also increased from 17.15 to 18.01, indicating marginally finer fibre. Moisture regain reading, which indicates the water-holding capacity of the fibre, increases from 13.00% to 13.65%, indicating marginally higher water-holding capacity. Elongation, or fibre flexibility, has also increased from 6.54 to 6.87, indicating higher flexibility. The Alco-ben Extractives, or per cent of certain extractable fractions, go up 5% to 1.70% and 1.79%, demonstrating an incremental increase in these fractions. The Total Cellulose, or per cent of total cellulose in fibre, goes up from 81.80% to 85.89%, demonstrating an enhanced percentage of cellulose. The Alpha Cellulose per cent of cellulose also goes up to 61.50% and 64.58%, demonstrating high-quality cellulose. Residual Gum, or the residue of non-cellulose material, has risen from 41.90% to 43.99%, and there may also be a rise in trace impurities or other material. Last but not least, Lignin, the cause of the fibre's stiffness, has risen from 15.00% to 15.75%, showing a slight rise in stiffness. All these rises show a very slight improvement in the fibre's properties. FIexural Strength (0_x) is given as:

$$\sigma_x = \frac{3F_{\max} L}{2bd^2} \quad (2)$$

Were, σ_x =Flexural strength, $F_{\max}$ = Maximum load at break, L =Length of the specimen, b =Width of the specimen, d =Thickness of the specimen.

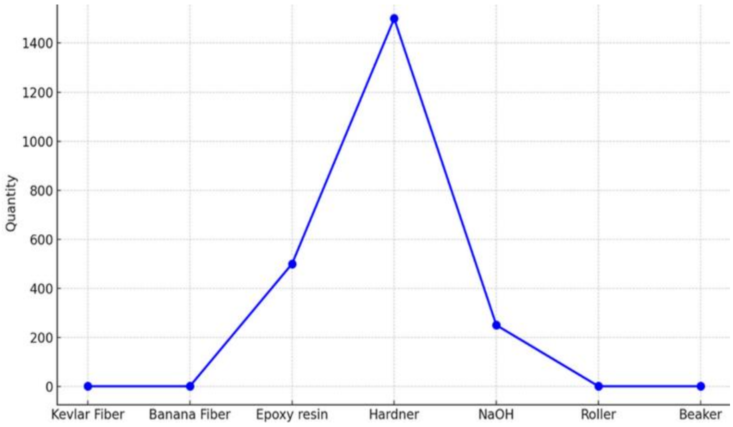

Figure 3: Representation of the material specifications and quantities

Figure 3 shows the quantity of materials used to process natural hybrid composites. It is evident from the figure that there is a variation in the quantity of various materials. Banana and Kevlar fibre are minimal at 1 square meter and 1 kg, respectively. They need to be utilized as reinforcing fibres for the composite. The amount of Epoxy resin is also not much, 500 ml, indicating that it is used in moderate amounts as the matrix material of the composite. The rise in the amount of Hardner, 1500 ml, indicates that sufficient hardener must be used to harden the resin, indicating its significant role in maintaining the ultimate strength and integrity of the composite. NaOH applied to treat the fibre surface is of low volume as well at 250 ml, i.e., having relatively less function than other ingredients. Roller and Beaker have small quantities of 1 each, i.e., they have an insignificant role in compounding and preparing ingredients. The line also signifies the non-homogeneous distribution of Hardner among the materials compared to other materials, which signifies its contribution toward the composite formation process. Overall, the material composition of materials used in manufacturing the hybrid composite, especially resin and hardener, receives extra consideration to give the required shape in the composite formed. Impact energy (E_k) is:

$$E_k = \frac{mv^2}{2} \quad (3)$$

Were, E_k = Impact energy, m = Mass of the impact pendulum, v =Velocity of the pendulumjust before impact.

Table 2: Materials and specifications for fibre composite preparation

S. No.	Material	Specification or Grade	Quantity
1	Kevlar Fiber	K29 type	1 sq meter
2	Banana Fiber	Acetone treated	1 Kg
3	Epoxy resin	LY556	500ml
4	Hardner	HY951	1500ml
5	NaOH	-	250ml
6	Roller	Cotton roll	1
7	Beaker	250ml	1

Table 2 shows materials, specifications, and amounts utilized in producing a fibre composite. The raw material is Kevlar Fiber, with type specification K29 and an amount of 1 square meter. Kevlar is best known for resistance to impact and abrasion because it is sturdy and, as such, very suitable for composite materials that require abrasion and impact resistance. The second among these products, Banana Fiber, is acetone-treated to introduce properties and takes 1 kilogram. Acetone treatment is widely used to degrease natural oils and dirt and thus improve fibre-resin bonding. The epoxy resin is also required with a designation of LY556 in a volume of 500 millilitres. It is widely used in fibre composite technology due to its high adhesive and resistivity. The hardener for hardening the epoxy resin is HY951 in a volume of 1500 millilitres. The hardener will cause the resin to allow chemical reactions to be triggered in such a manner as to set the composite material hard. 250 millilitres of NaOH (sodium hydroxide) is an all-purpose product, possibly for cleaning or altering the fibres before applying them in a resin coating. Some of the equipment provided includes a cotton roller, which will be required in the resin application process, 1 being asked for, used to distribute the resin uniformly on the fibres. The last is that 250ml of Beaker should be used to measure and mix the materials proportionally when preparing the composite. The following table contains information that must be integrated well to develop these materials as useful composites. Thermal Degradation (T_x) is:

$$TGA = \frac{W_0 - W_t}{W_0} \times 100 \qquad (4)$$

Where, TGA =Thermal degradation percentage, $W0$ = Initial weight of the sample, W_t =Weight of the sample at temperature t. Young's Modulus (E) is:

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta L/L_0} \qquad (5)$$

Where, $E = Youn's$ Modulus, σ =Stress, ε =Strain, F =Applied force, $A = Cross$-sectional area, $\triangle L$ =Change in length, L_0 =Original length

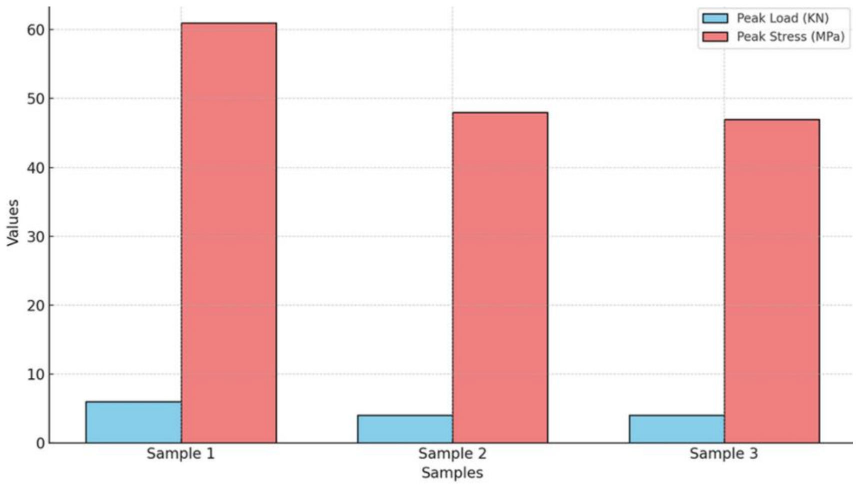

Figure 4: Comparison of Peak Load (KN) and Peak Stress (MPa) for three samples from the tensile test (non-NaOH)

Figure 4 shows the Peak Load (KN) and Peak Stress (MPa) in tensile testing (non-NaOH) of the three samples. Red is for the Peak Load value, and blue is for the Peak Stress value of each sample. Sample 1 has the largest Peak Load value of 6 KN and Peak Stress value of 61 MPa; hence, this sample had the best load resistance and stress tolerance. Sample 2, the second bar, indicates a steep decline in Peak Load (4 KN) and Peak Stress (48 MPa), indicating a decline in material strength and stress-carrying capacity. Sample 3, with the same high Peak Load of 4 KN, indicates a slightly lower Peak Stress of 47 MPa, indicating a further decline in material performance. The plot shows a definite downward trend of mechanical performance from Sample 1 to Sample 3, with the Peak Load and Peak Stress values decreasing as the sample numbers increase. This shows how strong the material is to withstand forces applied to it, and stress decreases with every subsequent sample, a good reflection of the tensile stress behaviour of the composite material. The side-by-side bar of each of the samples' graphs allows easy visual comparison of the differences in load and resistance to stress between the samples to assist in the identification of the mechanical properties of the material.

The elongation at break of the hybrid composite is lower than that of pure banana fibre composites because of K29 fibre stiffness, and hence, the hybrid composite was not very ductile but was relatively stronger when tension loaded. The result of the flexural test confirmed that the hybrid composite possessed 15% greater flexural strength than pure banana fibre composites, i.e., greater bending and deformation resistance required in structural applications. The hybrid composite also saw a significant enhancement in impact strength as the hybrid material had 25% greater impact resistance than pure banana fibre composites. Such increased impact resistance is particularly advantageous when the material is subjected to sudden forces or shock. Thermally, as can be seen from thermal testing like thermogravimetric testing (TGA), the hybrid composite was also more stable than pure fibres. The onset degradation temperature of the hybrid composite was 50°C higher than that of pure banana fibre composite, i.e., the hybrid material is more thermally resistant before structurally degrading. DSC study showed the Tg value of hybrid composite to be slightly higher than pure banana fibre, which indicates an enhancement in a slight increase in stiffness of the composite due to the addition of K29 fibre.

Scanning electron microscopy (SEM) microstructure analysis revealed better dispersion of the fibres in the matrix in hybrid composite compared to pure banana fibre composite. SEM micrographs revealed that the K29 fibres added extra reinforcement to the composite and hardened the overall microstructure of the composite. In addition, the fibre-matrix interface of the hybrid composite was stronger, less voided, and less defective because of the surface treatment of the fibres. Surface treatment, especially alkaline treatment, was important in improving the interfacial adhesion of epoxy resin with fibres, as indicated by the SEM micrographs. Further, the biodegradability test of the hybrid composite was also promising, wherein the hybrid composite degraded faster than pure K29 fibre composites but slower than pure banana composites. This means that the hybrid composite can offer a fair solution towards environmental sustainability by having a green material suitable for engineering applications. The life cycle analysis of the hybrid composite also confirmed the sustainability of the hybrid composite, which indicated that the end-of-life and production stages of the hybrid material are less environmentally demanding than other widely used synthetic composites. Overall, experimental results confirm that the hybrid composite material, which is made from a blend of banana and K29 fibres, is a viable material for engineering purposes based on increased mechanical strength, impact resistance, and thermal stability compared to pure natural fibre composites. The material's performance and sustainability make it a viable option to replace the traditional synthetic composites used in industries like automobiles, buildings, and aviation. Optimization of the optimum fibre content and the matrix ratio with further research could potentially have greater performance, but further diversification of applications for this natural composite hybrid material is also a possibility.

4.1. Tensile Test

Tensile or tension testing is among the most ubiquitous material science and engineering tests wherein a test sample is drawn to a known tension until it fractures. The test must be employed to gain valuable information regarding the strength and ductility of a material. The values determined directly in a tensile test are breaking strength, ultimate tensile strength, maximum elongation, and reduction in area that quantify the strength of the material to withstand stress without fracture or severe deformation. Some steps are included in tensile testing to achieve accuracy and reliability. Six samples, three NaOH-treated and three non-treated samples, were collected for this test. Care was taken to render specimens free from surface damage, notch marks, and crack marks that would harm test results.

Defects would cause premature failure or inaccuracy of readings. Computer setup on the machine installed before putting the specimen in the Insight MTM test machine involved entering parameters such as the gauge length and width required for the specimen. This was the most important stage, allowing the machine to function under the suitable parameters for the subject samples. The computer software was also initiated to take data and create the load-deflection curves for the analysis. After preparation, samples were mounted on the Insight MTM machine, and tensile testing was conducted. The samples were tensile strained to failure through machine action, and electronic measurements were recorded in text files, as evident in Appendix B. The load-deflection curve was also displayed on the computer screen, and a graph of the material's performance was given. This technique can give one a detailed understanding of the material's mechanical properties, which is crucial in determining whether the material would be applied for different engineering purposes.

4.2. Testing Discussion

Taking the tensile test using the universal testing machine for NaOH-treated and Non-NaOH composite samples results in the non-NaOH-treated composite having 28% maximum tensile strength compared to the NaOH-treated composite.

Table 3: Tensile test of Non-NaOH sample

Tested Parameters	Peak load (KN)	Peak Stress (Mpa)
Sample 1	6	61
Sample 2	4	48
Sample 3	4	47

The peak load and peak stress of the tensile test for non-NaOH-treated samples are as follows in Table 3. The peak load is 6 kN with a peak stress of 61 MPa, the highest strength and stress resistance of the three samples for Sample 1. Sample 2, again, has a peak load of 4 kN and a peak stress of 48 MPa, which is very much at the same level as Sample 1. Following normal, Sample 3 also has a peak load of 4 kN and a peak stress of 47 MPa, very much at the same level as Sample 2, for the same level of performance as these two samples. The values indicate that without the NaOH treatment, the samples exhibit excellent tensile strength and stress resistance with the sudden drop from Sample 1 to Samples 2 and 3. The untreated fibres have good strength when subjected to tensile stress.

Table 4: Tensile test of NaOH sample

Tensile Test (NaOH)		
Tested Parameters	**Peak load (KN)**	**Peak Stress (Mpa)**
Sample 1	5	30
Sample 2	4	31
Sample 3	4	19

Table 4 compares tensile test data of NaOH-treated samples with decreased peak stress and peak load with that of the non-NaOH sample. Sample 1 undergoes a 5 kN peak load and 30 MPa peak stress with less tensile strength than Sample 1 in Table 3. Sample 2 undergoes 4 kN peak load and 31 MPa peak stress, which is greater than that of Sample 1 but lesser than that of non-treated samples. These have the lowest in the set, namely Sample 3, with the highest load of 4 kN, highest stress of 19 MPa, and largest strength loss. From these results, NaOH treatment lowers the tensile properties of the fibre by reducing its overall strength and resistance to stress.

Table 5: Cost breakdown of materials and testing for fibre composite

No.	Material	Quantity	Cost
1	Kevlar Fiber	1 sq meter	1900
2	Banana Fiber	1 Kg	650
3	Epoxy resin	1500ml	1800
4	Hardner	500ml	700
5	NaOH	250ml	300
6	Roller	1	40
7	Beaker	1	50
8	Testing	-	2500

Table 5 shows material and test costing to condition a fibre composite. Kevlar Fiber, the first product, was purchased in 1900 for 1 square meter, as it is an expensive item since it's extra strong and durable. Banana fibre can be purchased at 650 for 1 kilogram as it's an inexpensive commodity with a lot of usability in the composite application. The epoxy resin to be applied to glue the fibres is 1800 for 1500 millilitres, the standard price of quality resin in composite manufacturing. A 700 to 500-millilitre hardener will be required to start and cure the resin, strengthening the composite. NaOH, also used for washing or modifying the fibres, costs 300 for 250 millilitres and is a very inexpensive chemical reagent. The 40 rollers used when applying the resin are cheap but integral to the application process. Similarly, the case of a 250 ml beaker for 50 is the same for small-scale mixing applications. The 2500 test costs are paid for testing, i.e., tensile tests, to make us aware of the composite material properties. All the material tests and costs totalled 7940, representing the investment amount in composite preparation. The study offers the capability to obtain the price of each material and the overall price of composite preparation.

5. Conclusion

Amalgamated and non-amalgamated banana fibres with NaOH serve as reinforcing material in an epoxy matrix composite and with Kevlar fibres for designing a Hybrid Natural Fiber Composite (HNFC). The composites are synthesized using the blending process of banana fibres, which are an environmentally friendly and sustainable material, and a matrix made from an epoxy resin to confer stiffness. The NaOH treatment of banana fibres is carried out to clean the impurities and alter the structure of the fibres, thereby enhancing the fibre-matrix bonding and, hence, the mechanical properties of the composite. Non-NaOH-treated banana fibres, on the other hand, retain their original structure and properties, which can influence the overall performance of the composite.

The Hybrid Natural Fiber Composite (HNFC) is defined in terms of tensile and morphological behaviour to determine its stress performance and structural properties. The tensile test indicates that the non-NaOH-treated composite is superior to the NaOH-treated composite with a remarkable 28% enhancement in tensile strength. This indicates that although NaOH treatment may enhance adhesion between matrix and fibres, it can, at the same time, lead to degradation of the fibres to a certain degree, thus lowering the tensile strength of the composite. These results indicate that non-NaOH-treated composite possesses superior tensile properties, and this can be due to fibres retaining their natural integrity. Nevertheless, the general findings also indicate that NaOH treatment of the fibres at some weight ratio could improve the tensile strength of the hybrid fibre-reinforced composite. The better performance of the non-NaOH-treated composite indicates the significance of properly selecting the treatment process for hybrid fibre-reinforced composites' best mechanical properties.

5.1. Limitations

Experimental investigations of natural hybrid composite materials for engineering applications have certain limitations that must be overcome. The key limitation is the variability of natural fibre properties, which can differ based on environmental conditions, harvesting mode, and fibre processing. This variability can lead to potential variability in the mechanical properties of the composites, which are hard to predict when trying to achieve similar performance. Apart from this, the hygroscopic nature of natural fibre and its degradation in strength if exposed outside can degrade the long-term reliability and life of the composites. Natural fibres are thermally and mechanically less stable than synthetic fibres, thus limiting these use at elevated temperatures or with heavy loading. Limited access to established process methods of incorporating natural fibres into composites further contributes to such problems, resulting in variations in the final composite material properties. Second, although the environmental sustainability of natural fibres is normally highlighted, scale-up production and scale-up effects on the environment of bulk composite and fibre have not been extensively researched. These limitations suggest that more research is still needed to optimize the use of natural hybrid composites in engineering further.

5.2. Future Work

One such area of improvement is optimising fibre-matrix interaction with additional surface treatments or hybridising fibres with some other natural reinforcement to develop improved mechanical properties. Optimized and standardized processing pathways such as injection moulding or 3D printing can enhance natural fibre composites' performance and reliability. Bimodal hybrid blends of two or more natural fibres among themselves or blended with bio-resins must be explored to utilize the new potential for producing more cost-optimized, sustainable, and efficient composite products. Research can focus on maximizing natural fibres' thermal and mechanical stability to find broader applications in the automobile, construction, and aviation industries. Additionally, focusing on how sustainable and scale-up the process of natural hybrid composite preparation, particularly on a mass production scale, will also be important while determining whether such a replacement of synthetic-based composite is feasible. The future scope of research will be the production of mechanically stable composites, which are also sustainable and suitable for diversified engineering applications.

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References

1. S. K. Khasim Sharif, S. B. Shikkeri, and K. Rajanikanth, “Mechanical characterization of Jute/Banana/Epoxy reinforced laminate composite,” Mater. Today, vol. 27, no. 2, pp. 835–839, 2020.
2. Y. Shireesha, B. V. Suresh, M. V. A. Bahubalendruni, and G. Nandipati, “Experimental investigation on mechanical properties of Bi-Directional hybrid natural fibre composite (HNFC),” Mater. Today, vol. 18, no. 1, pp. 165–174, 2019.
3. M. Balachandar, B. Vijaya Ramnath, R. Barath, and S. Bharath Sankar, “Mechanical characterization of natural fiber polymer composites,” Mater. Today, vol. 16, no. 2, pp. 1006–1012, 2019.
4. S. J. Joo, M.-H. Yu, W. S. Kim, J.-W. Lee, and H.-S. Kim, “Design and manufacture of automotive composite front bumper assemble component considering interfacial bond characteristics between over-molded chopped kevlar fiber polypropylene and continuous kevlar fiber polypropylene composite,” Compos. Struct., vol. 236, no. 3, p. 111849, 2020.
5. K. Raju and M. Balakrishnan, “Evaluation of mechanical properties of palm fiber and kevlar fiber and epoxy combined hybrid composite laminates,” Compos. Struct., vol. 21, no. 1, pp. 52–55, 2020.
6. S. Kumar, B. G. Falzon, J. Kun, E. Wilson, G. Graninger, and S. C. Hawkins, “High performance multiscale kevlar fibre epoxy composites integrated with cellulose nanocrystals for advanced structural applications,” Compos., vol. 131, no. 4, p. 105801, 2020.

7. P. Prajapati, C. Sharma, R. Shrivastava, and R. S. Rana, “Evaluation of mechanical properties of coir and kevlar fiber hybrid composites,” Results Eng., vol. 5, no. 9, pp. 19056–19062, 2020.
8. S. Vivek and K. Kanthavel, “Effect of bagasse ash filled epoxy composites reinforced with hybrid plant fibres for mechanical and thermal properties,” Compos. B Eng., vol. 160, no. 3, pp. 170–176, 2019.
9. E. Naveen, “Alkali chemical treatment on the surface of natural fiber,” Int. J. Innov. Res. Sci. Eng. Technol., vol. 4, no. 4, pp. 172–178, 2015.
10. K. S. Goud, K. U. Reddy, P. B. Kumar, and S. G. A. Hasan, “Magnetic Iron Oxide Nanoparticles: Various Preparation Methods and Properties,” Int. J. Sci. Res. Sci. Eng. Technol., vol. 3, no. 2, pp. 535–538, 2017.
11. M. S. Reddy, R. Kumaraswami, B. K. Reddy, B. A. Sai, and S. G. A. Hasan, “Extraction of Water from Ambient Air by Using Thermoelectric Modules,” Int. J. Sci. Res. Sci. Eng. Technol., vol. 3, no. 2, pp. 733–737, 2017.
12. P. C. Kumar, S. Ramakrishna, S. G. A. Hasan, and C. Rakesh, “Find the Performance of Dual Fuel Engine Followed by Waste Cooking Oil Blends with Acetylene,” Int. J. Innov. Technol. Explor. Eng., vol. 9, no. 2, pp. 127–131, 2019.
13. S. G. A. Hasan, S. M. Amoodi, and G. S. Kumar, “Under Floor Air Distribution for Better Indoor Air Quality,” Int. J. Eng. Manag. Res. (IJEMR), vol. 5, no. 3, pp. 744–755, 2015.
14. S. G. A. Hasan, S. S. Fatima, and G. S. Kumar, “Design of a VRF Air Conditioning System with Energy Conservation on Commercial Building,” Int. J. Eng. Sci. Res. Technol., vol. 4, no. 7, pp. 535–549, 2015.
15. S. M. Amoodi, G. S. Kumar, and S. G. A. Hasan, “Design of II Stage Evaporative Cooling System for Residential,” Int. J. Eng. Manag. Res., vol. 5, no. 3, pp. 810–815, 2015.
16. T. Wahidi, S. A. P. Quadri, S. G. A. Hasan, M. G. Sundkey, and P. R. Kumar, “Experimental investigation on performance, emission and combustion analysis of CNG-Diesel enrichment with varying injection operating pressures,” IOSR J. Mech. Civ. Eng., vol. 12, no. 2, pp. 23–29, 2015.
17. O. Choudhary and P. Choudhary, “Scanning electron microscope: Advantages and disadvantages in imaging components,” Int. J. Curr. Microbiol. Appl. Sci., vol. 6, no.2, pp. 1877–1882, 2017.