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Mechanical Properties and Characterization of Hybrid Polyester Composites Reinforced with Alkali-Treated Kenaf, Silicon Carbide, and Bamboo Fibers for a Variety of Applications

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Composites of alkaline-treated Kenaf (KF) and bamboo fiber (BF) reinforced with Silicon carbide (SiC) and polyester are described here with respect to their tensile, flexural, compression, impact, and hardness characteristics. The process of creating hybrid composite materials that are more effective for use in many contexts around the world is ongoing. However, natural fiber composites have the potential to replace manufactured fiber composites as an alternative design material due to its exceptional and extensive range of inconsistency. Because of their wide variety of features and characteristics, natural fiber composites (NFC) can be difficult to deal with. Here, BF serves as the foundational material, with SiC and KF serving as the filler components. We kept the BF weight percentage fixed and altered the other two fiber fillers. The NFC was subjected to mechanical property tests following ASTM guidelines after being hand-layup-created. These tests included tensile, compression, flexural, impact strength, and hardness testing. Addition of natural fibers and fillers improved the mechanical qualities indicated above, according to the trials. The effective resistance performance is also attributed to the improved interlinking capability of the NFC and polyester matrix. Composites like these have applications in many areas of engineering.

Keywords: Kenaf; flexural; mechanical properties; SiC; bamboo fiber; kenaf fiber

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The many benefits of bio composites, including their reduced weight, resilience to corrosion, high fatigue resistance, and ease of assembly, are making them an integral component of modern materials [1]. They are used in the construction of aircraft, electrical packaging, medical devices, spacecraft, and even building materials for homes. As more and more people are becoming conscious of the need to prioritize sustainable development and environmental protection, polymer composites reinforced with biodegradable natural fibers have been increasingly popular, replacing synthetic, non-biodegradable fibers such as carbon, graphite, and glass [2]. The lattice of a bio composite is formed by a variety of materials, including jute, coir, bamboo, pineapple, ramie, bamboo, banana, bagasse, and many more. Common filament composites are eco-friendly, thin, low-effort strands with high explicit characteristics. All around the globe, state-of-the-art biocomposites materials are undergoing continuous improvement [3]. Household furniture, houses, fencing, decking, ground surface, lightweight vehicle segments, and sports supplies are just a few examples of the everyday items that can benefit from this alternative approach of building bio composites [4].

It is an ongoing process to develop bio composite materials with better performance for use all over the world. To bridge the knowledge gap regarding the mechanical characteristics of epoxy-reinforced NFC like flexural, compression, tensile, impact, and hardnessit is essential to characterize these materials using a wide variety of fundamental variables [5]. Only then will they be able to be used in engineering applications. In order to make NFC that can endure the stresses of structural loading applications in civil engineering, industrial, and automotive engineering, researchers are hoping that the results will inform the development of future generations of NFC. Various tests were conducted on hybridized kenaf/bamboo/ glass-reinforced HDPE composites, including tensile, flexural, and impact experiments [6]. The flexural strength of the composite generally followed the Rule of Mixture (ROM), in contrast to its inverse proportionality in tensile and impact strengths. The impact strength of the composite, however, increased as the fiber length increased. Fiber length, fiber percentage, and surface modification were studied in relation to the mechanical properties of SiC strengthened polymerics composites [7]. Composites' Young's modulus and tensile strength increased as fiber content increased, in line with the law of mixtures. Mechanical properties of high impact polystyrene composites treated with sodium hydroxide (NaOH) and reinforced with tamarind shell powder [8]. The effects of treating with a solution of alkali (NaOH) at varying concentrations (0%, 2%, and 4% NaOH) were examined in this study. When compared to the other concentrations, the mechanical property

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value was highest for the 4% NaOH solution utilized for the brief SiC treatment [9]. Theoretically, the reinforcing qualities of bamboo fiber could be useful in a variety of thermosets, including polyethylene, polystyrene, natural rubber, and epoxy, phenol-formaldehyde, and polyester [10]. While polyester matrix reis composites have a lot of name recognition, SiC-reinforced polyester composites have received far less research attention [11]. Due to the composites' durability, scientists noticed that unidirectionally aligned SiC - polyester composites had an enhanced microfibrillar angle of the fibers [12]. Polyurethane (PVC) composites with added kenaf, sisal, pineapple and bamboo have their mechanical characteristics detailed [13]. The hardness, flexural strength, impact resistance, and in-plane tensile strength of the natural composites were the mechanical parameters that were determined. Over time, the mechanical qualities have been steadily improved by incorporating fibers into epoxy matrix composites [14]. Researchers have looked at two alternative fiber-to-volume ratios10:4 and 10:5% to determine the mechanical characteristics of polyester reinforced with sugarcane fiber [15]. These results demonstrate that the addition of composites made of bamboo fibers increases the materials' pliability, flexural strength, impact resistance, and hardness. Composites made of unsaturated polyester and bamboo fiber are compared in terms of their mechanical properties [16]. Composites made of sisal, bamboo fiber, and polyester-reinforced jute were described in great depth with regard to their mechanical properties. Mechanics testing consistently showed better results when using natural fibers. One reason for the effective resistance capabilities is the strong link among the plant fibers and the polymeric matrices. Natural fibers often undergo an alkaline treatment, which is a common chemical process [17]. The tensile strengths of short polyethylene films reinforced with sugarcane fibers were recorded, along with the outcomes of various chemical treatments [18]. The films were either randomly or unidirectionally oriented. We have also successfully applied this technique to bamboo fibers in the past. None of the researchers mentioned above have actually used SiC, KF, or BF composites in their studies. All three materials SiC, BF, and KF have their own distinct chemical and mechanical characteristics. Automobile, construction, and maritime applications are just a few of the many that will benefit from the distinct qualities of the aforementioned three fibers. The continued improvement of NF composites for use in biodegradable environments is the focus of this effort, nevertheless. Kenaf fiber, silicon carbide, and bamboo strand reinforced polyester composites are the topic of this article.

To separate the two fibers, researchers used two distinct extraction methods: BF, and KF. To further enhance the mechanical properties, BF, and KF fibers were alkali treated before being utilized in the manufacture of composites. In a preliminary study, the effects of several strand extraction procedures, handling techniques, mechanical qualities, and depictions of common filaments with polyester lattice were contemplated. Utilizing scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR), investigations into the fibers' characteristics were conducted.

MATERIALS AND METHODS

Materials used in this experimental fabrication included polyester resin, KF, SiC, and BF, Polyester resin, and hardener HY951. Each of the three comes from Go Green Enterprises in Chennai, Tamil Nadu, India. Kovai Cheenu Enterprises, Coimbatore provides the hardener, polyester resin, and Methyl Ethyl Ketone Peroxide (MEKP). Many different kinds of natural fibers have their physical properties listed in Table 1.

Table 1. Characteristics of natural fibers

Physical properties	Bamboo	Kenaf
Lignin (%)	20 – 30	9 – 7
Cellulose (%)	60 – 70	55 – 65
Density (g/cm^3)	1.2 – 1.4	1.2 – 1.5
Tensile strength (MPa)	200 – 500	250 – 600
Elongation at break (%)	20 – 25	1.5 – 1.4

Preparation of Fibers

A method known as decortication was employed to separate the fiber from the bamboo. To achieve this, we used a stick with a smooth edge to manually crush and beat the leaves until only their fibers remained. To get rid of any remaining chlorophyll, leaf fluids, or sticky particles (hemicelluloses), the fibers were thoroughly rinsed with water after extraction. A mixture of 40 grams of alkali and 100 milliliters of distilled water was prepared for the purpose of treating bamboo fiber with alkali treatment. A magnetic stirrer was used to agitate the mixture at 60 degrees Celsius for a duration of 15 minutes. Then, the mixture was supplemented with 5 grams of bamboo fiber. After a one-hour immersion in a solution of alkali (NaOH), the fiber was extracted and then dried at 60°C for four hours [19]. Despite the superior mechanical quality of kenaf regular fibers, they are not currently being utilized effectively due to a lack of information. Dissolving a NaOH pellet according to the specified fixing was part of the soluble treatment. For instance, 40 grams of sodium hydroxide pellet was dissolved in 1000ml of purified water to create a 4% NaOH solution. The kenaf filaments were sliced to a length of around40cm and then immersed in the NaOH solution as directed, with distilled water being used to flush them out afterwards [20]. To determine the alkalinity, pH paper was soaked in the mixture. In order to achieve a pH of 7, the strands were rinsed. Broiler drying, followed by a 24-hour period at 60°C, was the last step in the fundamental treatment.

Fabrication of Composites

The dimensions of the metal mold utilized in the present work were 300×300×3 mm. This mold was used for the hand lay-up fabrication of the composite material. After applying a layer of wax and remover to the inside and outside of the mold and walls, we let them dry. To get ready to manufacture a composite material, the mold is set at atmospheric condition.

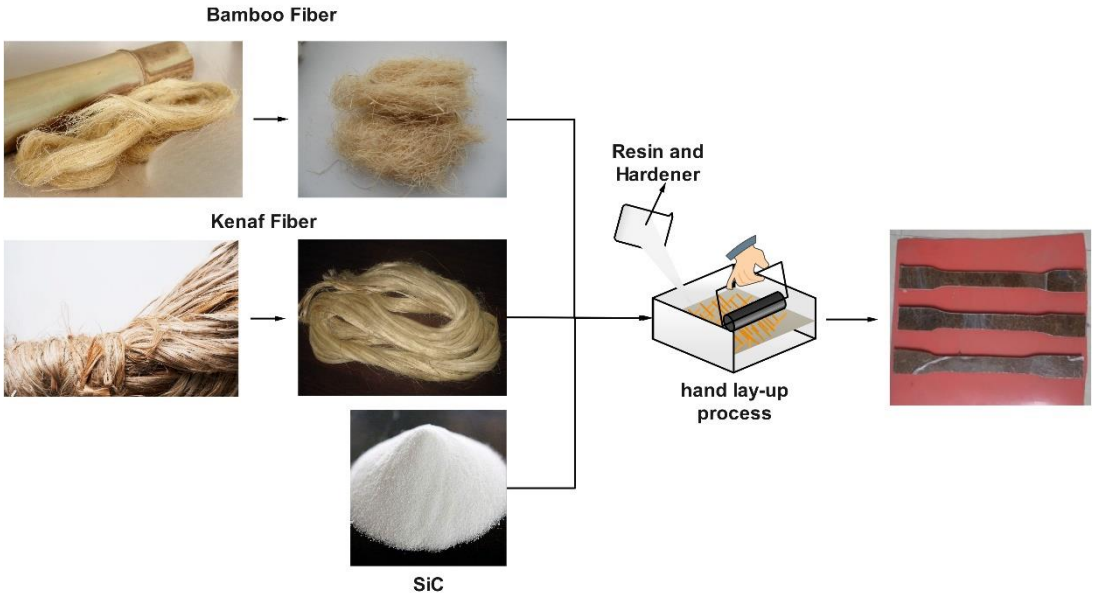

Figure 1. Fabrication of bio composite sample used in this study.

Table 2. Composition of materials used in the composite sample.

Designation of specimens	Bamboo fiber (BF)	Kenaf (KF)	Silicon Carbide (SiC)
S1	50	48	2
S2	50	46	4
S3	50	44	6
S4	50	42	8
S5	50	40	10

To prepare the natural fibers for fabrication, they are first rinsed in the acetone thinner. That gets rid of any contaminants and prepares them for binding with the resin. A method for impregnating composite constructions was employed, which involved hand lay-up. A polyester suspension was used to wet BF, KF, and SiC in a mold using this method. The mold was impregnated with a small amount of resin, and then the hybrid fiber stacks were carefully arranged in a random manner. It takes around 48 hours for the resin to dry after being blended with the fibers in the open air under the blazing sun. Mounting the second layer is necessary prior to the resin drying. For an additional layer, the procedure is likewise repeated. We use a roller to spread the polyester resin evenly across the surface, and then we gently squeeze out the air bubbles that formed between the layers while we were making it. Pressing the specimen at 32ºC, 6 MPa, and 65% relative humidity results in the next step. Before cutting off the necessary-size test specimens from the sheet, the composite specimen was cured at 65ºC for 60 minutes to guarantee full curing. Extra resin and fiber edges on specimens have been appropriately ground down to size according to mechanical test specifications. Shown are the composite specimens' compositions and their designations. Table 2 shows that. The steps required to construct the hybridized composite samples are illustrated in Figure 1.

Mechanical Properties

Tensile Properties

A hand shaper is used to form the prepared example into the required size, and then salt paper is used to clean the edges. It follows the specifications laid out by ASTM D3039. The yielding test is conducted using a 75 mm measure length Instron Universal testing machine (UTM) with a 5 mm/min crosshead speed. The dimensions for the tensile test, according to ASTM D638, are 250×25×3 mm. After positioning the test sample in the UTM, the next step is to apply strain until the material breaks. A portion of the increase in check length is then recorded as the strength. The measurement segment's extension in relation to the applied power is documented during pressure application. As a demonstration of the growth in measurement length, the malleable power is preserved.

Flexural Strength

To determine the flexure of a specimen, this test employs a three-point bending method. An analogous pliable testing apparatus has presided over flexural tests. The flexural test specimen has the following dimensions: 125×12×3 mm, as per ASTM D790. As a means of gauging the composites' bending quality, this examination employed the world-renowned 3-point flexural test. A crosshead speediness of 2 mmmin^{-1} and a range of 70 mm span were the parameters of the machine. The test example is put through its paces in the UTM and powered until it snaps or cracks. We utilized five different sizes of the constant burden to get the estimations for each scenario.

Compression Strength

The ability of a material to remain intact when subjected to stress is an important and frequently utilized property. This quality is useful in a number of contexts. Compressive quality is a measure of how close a material is to completely failing under uniaxial compression. It is common practice to use compressive test procedures to estimate the compressive quality. This analysis also makes use of the apparatus utilized in tensile testing. For the compression test, the sample's size is 60×60 mm.

Impact Strength

In order to perform the impact test, the specimens are prepared and measured in accordance with the ASTM-D 256 standard. The dimensions of the Izod specimen that are required for testing are 60×12×3 mm. A test machine is used to stack the specimen and then let it swing on a pendulum until it breaks or fractures. One way to evaluate the yield quality and durability of a material is to conduct an impact test, which determines the energy required to shatter the material. Using the impact test, one may examine how the strain rate affects the material's break and ductility. By measuring the sample's energy consumption during the break in J/m^2, this test provides a quantitative value.

Hardness

A Shore D hardness tester is used to conduct the hardness test. The standard procedure for the beach (durometer) hardness tester is performed in accordance with ASTM D2240. The standard for all samples used for hardness testing is 40×12×3 mm in size. The resistance of a material to localized plastic distortions brought about by mechanical indentation or wear is measured by its hardness.

RESULTS AND DISCUSSIONS

Tensile Properties

The biocomposites tensile characteristics were shown in Figure 2(a) and 2(b). Assuming uniform fiber stacking, polyester composites always exhibit improved ductile characteristics. S1, S2, S3, S4, and S5 NFC composites have significantly improved elasticity. Both the elasticity and the tensile modulus increase continuously up to the material's maximal load carrying capacities. By comparing the results of the various composite combinations, it is clear that the 50% BF, 42% KF, and 10% SiC (Sample S5) polymer

composites are the most effective. Because alkali treatment can create a rough surface topography while simultaneously removing both natural and man-made contaminants, this is the result. Composite mechanical characteristics and fiber matrix interface adhesion are both enhanced by this design. Because of the rough surface, the fiber and matrix are more strongly bonded at the contact [21]. A progressive rise in the fiber contents of both KF 40% and SiC 10% results in an increase of the composites' tensile characteristics. The tensile properties of fiber sample A, which has not been treated, are extremely low. Findings for randomly oriented solution blended composites show that extreme stiffness initially decreases at 42% KF fiber content and then increases with increasing fiber concentration. With 42% fiber content, the composite may lose some of its elasticity due to the fiber acting as a structural defect. When fiber stacking is low, the network becomes susceptible because of non-fortifying debonded fibers, which occurs as a result of inadequate strand management and extremely low strain in the grid at low levels.

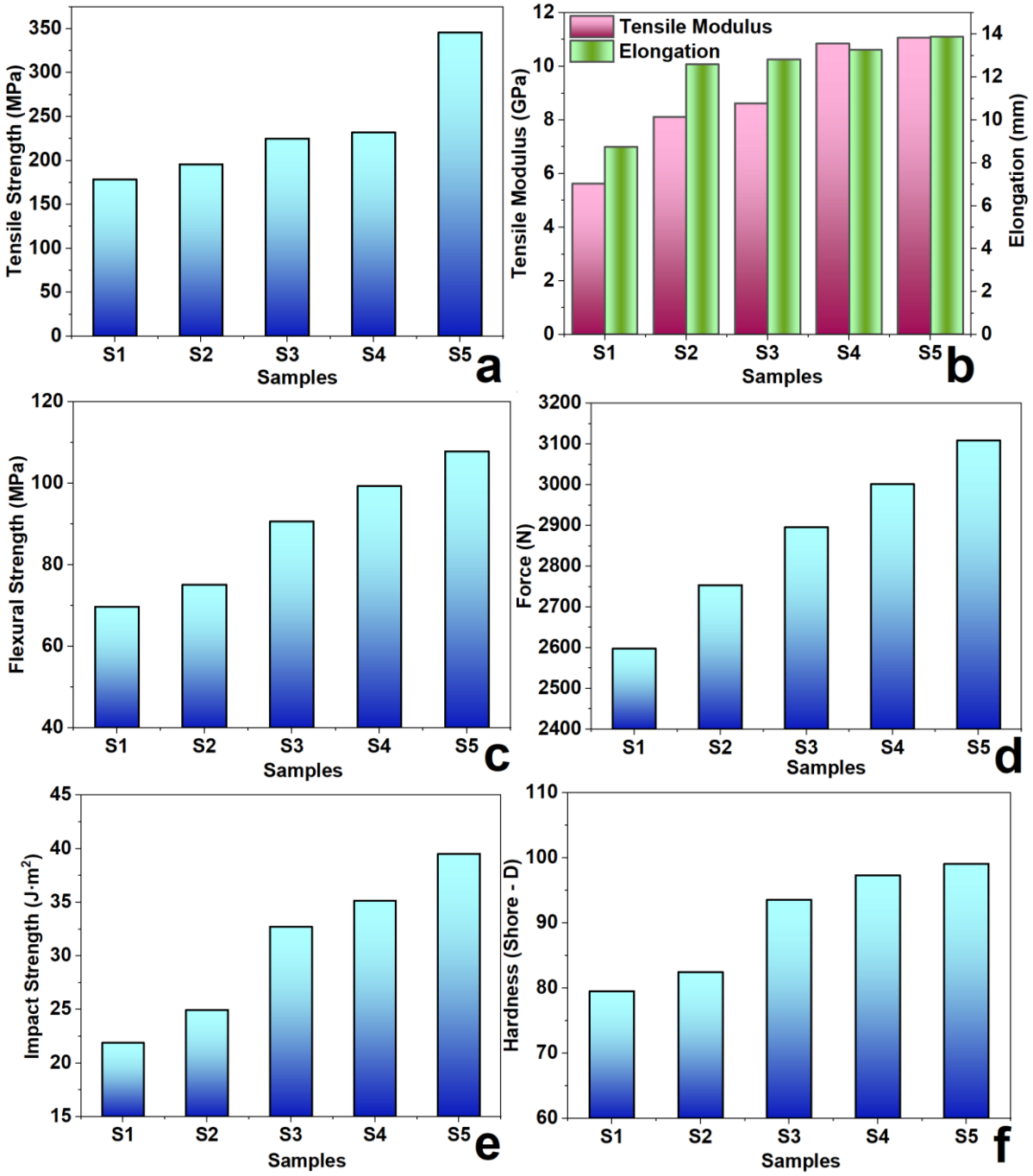

Figure 2. Evaluation of (a) Tensile strength (b) Tensile Modulus, Elongation (c) Flexural strength (d) Compressive force (e) Impact strength and (f) Shore- D hardness of hybridized composites.

Table 3. Results on tensile properties of various composites.

Sample	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation at break (mm)
S1	178.63	5.62	8.74
S2	195.76	8.12	12.59
S3	224.96	8.63	12.83
S4	231.85	10.85	13.27
S5	345.85	11.07	13.88

An increase in the fiber focus leads to a more uniform distribution of applied stress and a boost in composite strength [22]. The strength of a composite material can be increased or decreased by incorporating natural lignocellulose fibers into a polymer matrix. The strength can be enhanced by using lignocellulosic fibers because they are often able to support forces transmitted by the polymer. Matrix interface adhesion and filler dispersion improve the mechanical characteristics of fiber-based natural composites. With a maximum SiC weight percentage and a minimum KF weight percentage, the results demonstrate that polymer composites retain their tensile performance. Composites' tensile strength and modulus of elasticity are affected by the presence of KF, which can increase by 48% and decrease by 2%, respectively. Since the produced fibers are not uniform in quality, the composites' strength is affected. As the fiber could not withstand the pressures imparted by the polymer matrix, the strength was deteriorating. Composites reinforced with natural fibers have better mechanical properties after being alkali treated, since this enhances the fiber-matrix contact and removes hemicellulose and lignin [23]. The tensile strengths of bio-composite materials are shown in Table 3.

Tensile Modulus

Tensile modulus is improved when SiC loading is increased and KF is decreased. As indicated in Figure 2(b), the tensile modulus for S5 increases at a quick rate and reaches 8.8 GPa as the quantity of SiC fibers increases. Tensile modulus, a measure of composite stiffness, is positively affected by SiC fiber insertion (Figure 2(b)). Specimens S1, S2, S3, and S4 had tensile strengths of 48.35%, 43.40%, 34.95%, and 32.96%, respectively, when compared with specimen S5. Increases of 18.64%, 12.71%, 9.32%, and 3.39% were noted in the tensile modulus.

Flexural Strength

Figure 2(c) indicates the findings of the flexural strength. Changing the SiC content and loading of KF fibers rises the flexural properties of the composites. An additional benefit of filler is an improvement in flexural characteristics. Elastic deformation was made possible by the increased stress transmission in the composites due to the strong connection among the matrix and the fibers. Aggregation results from interactions between filler and fiber, and matrix and filler interactions produce change with properties distinct from the added components. Interactions in bio-composites vary as a result of the Vander Waals force [24]. In order to improve the hybrid natural composites' flexural capabilities, strong hydrogen bonds were formed as a result of the epoxy matrix's increased polarity. At a fiber loading of 50% BF and 10% KF, the maximum flexural strength of 107.89 MPa is achieved. While comparing specimens S5, S1, S2, S3, and S4, the flexural strength has increased by 35.34, 30.32, 15.96, and 7.92%, correspondingly.

Compressive Strength

The compressive strength (CS) of a polyester resin is enhanced by adding fiber reinforcements. Incorporating natural fiber particles into the SiC reinforcement greatly increases its compressive strength, as seen in Fig. 2(d). S1, a composite sample with a higher percentage of KF particles, with a compression of 4.82 mm, withstood a minimum stress of 2598 N. Specimen S2 showed a tiny rise to 2754.3 N in compression load and a compression value increase of 4.67 mm. A compression force of 2896 N was applied to specimen S3, which resulted in a compression of 4.32 mm. S4 composite specimens can withstand loads up to 3002 N with a compressive strength of 4.29 mm. But sample S5, which has a low KF content and a high SiC reinforced polymer composite, could withstand a 3109 N stress and a 386 mm compression.

Impact Strength

Figure 2(e) displays the data showing that the impact strength of the composites rises steadily from S1 to S5. The IS of the composites is improved during manufacturing because the surface of the SiC and KF mix the polymeric composites and hybrid fibers. Increasing the amount of fillers has a greater effect on the impact attributes through the agglomeration property [25]. Specimen S5's maximum impact

strength was around 33.1 J/m^2 when the weight of the SiC and KF fibers was 40% and 10%, respectively. With each successive iteration, the impact strength of the S1, S2, S3, and S4 hybrid specimens rises: from 21.88 to 24.95 to 32.74 to 35.16 J/m^2. With each passing iteration, the S5 specimens' impact strength increases to 39.53 J/m^2. The impact resistance and fracture propagation resistance of the material are both improved by the strong adherence of the matrix and fibers. Specimen S5's maximum number of SiC fibers can have their contact area with the matrix increased by thoroughly impregnating the fibers with the resin. Enhanced load capacity and, by extension, a reduced commitment of fiber-related systems, such as fiber pullout, are responsible for the increase in impact strength. The low microfibrillar angle and high alpha-cellulose content of SiC are the reasons for its exceptional mechanical characteristics [26]. One application for SiC is as a reinforcing composite matrix, thanks to its exceptional properties. When comparing specimens S5, S1, S2, S3, and S4, the impact strengths of the enhancements are 44.65%, 36.68%, 17.18%, and 11.05% to correspondingly. In general, the more sturdy a material is, the higher its impact strength will be. It turns out that the filaments play a big part in the composite's effect barrier. Increased sway quality is the result of the two strands' complementary effects. As far as impact properties are concerned, hybridization results in a favorable impact.

Hardness

The hardness of hybridized composites grows progressively from S1 to S5, as seen in Figure 2(f) of the hardness data. Specimen S5, which comprises 40% SiC and 10% KF fibers, achieved a maximum hardness of approximately 99.14. The other specimens S1, S2, S3, and S4 are also a part of this set; their minimum hardness values are 79.56, 82.47, 93.62, and 97.35, respectively. The larger content of SiC fibers and the lower content of KF are the reasons why the hardness of specimen S5 is increased. The top surface of the NFC was covered with a material that had a higher quantity of SiC fibers interlinked with polyester resin. Polymer composites with two layers are shielded by SiC fibers with higher concentrations [27]. The improved distribution of SiC and KF fibers within the polyester matrix also results in higher interfacial adhesion. In comparison to specimens S1, S2, S3, and S4, specimen S5 shows an increase of 19.75%, 16.81%, 5.57%, and 1.81%, respectively.

Microstructural Analysis of Bio Composites

Using a JSM-5300LV SEM with a 10 kV, the structure of the PA6 composites is studied. When subjected to a tensile test, specimens S1 and S5 showed contrasting levels of tensile strength. The morphological tests use both the S5 (Maximum ductile) and S1 (lowest ductile) specimens.

Figure 3 shows the scanning electron microscopic image of sample S1 and S5 respectively. The morphological results demonstrate that the bio-composites contain an adequate amount of both natural fibers (NF) and synthetic polyester resin. The micrographs clearly show that the three fiber reinforced polymer composites are mixed uniformly. In the first scenario, fibers break and large particles are found. The presence of polyester resin on the fiber has not been detected. There was no interfacial failure but a significant improvement in fiber break-out length when the SiC and KF content was 10% and 40%, respectively, compared to when the SiC and KF content was 2% and 48%. Nevertheless, in this particular instance, remnants of the matrix continue to shield the fiber. This suggests that the fiber-polymer matrix link was intact and that the material qualities of the polymer matrix were the primary determinants of failure. The decrease in tensile and flexural strength of the filler loading is mostly caused by the uneven distribution of SiC fiber and its weak adherence to the natural fiber matrix [28]. Nevertheless, the inclusion of a bonding agent marginally enhanced both properties at a comparable filler loading. This is because adhesion is reduced between the 40% KF and 10% SiC concentrations. The tensile characteristics were improved by using a high SiC content and a low KF content. Improving the tensile strength of the polyester matrix by filler loading is primarily achieved by ensuring that the natural fiber matrix is evenly distributed. The improved ductility is a result of the 10% SiC and 40% KF properly adhering to the polymer matrix. A 2% filler loading and a weak interfacial bond between the fibers and the matrix are shown by the scanning electron microscopy (SEM) as fractured tensile fracture surfaces with unfilled spaces in the composite.

FTIR Analysis for Composites

A Shimadzu (8400S Model) spectrometer is used for Fourier transform infrared (FTIR) analysis, has a maximum resolution of 0.90cm^{-1}. The IR package, which includes the FTIR-8400S, is a 32-bit high performance FTIR program. Since S5 specimens had reached their maximum tensile strengths and tensile modulus, only S5 specimens were subjected to FTIR investigation. The primary FTIR bands of the doped S5 material are visible in Figure 4's curve.

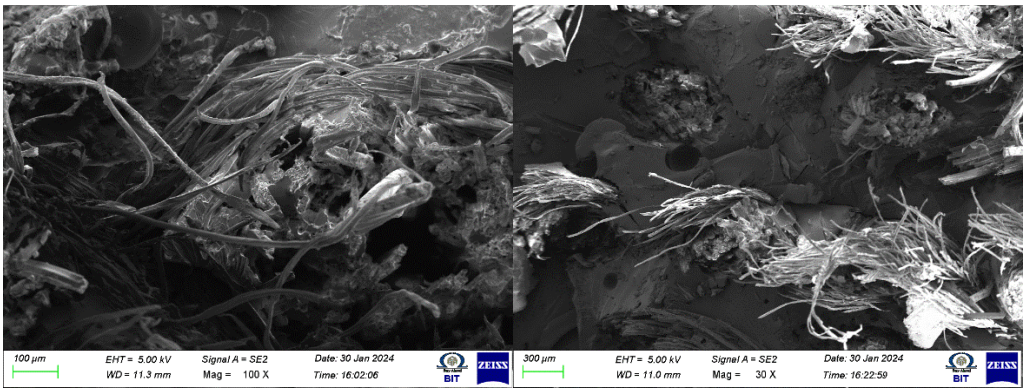

Figure 3. Scanning electron microscopic image of sample; (a) S1 and (b) S5.

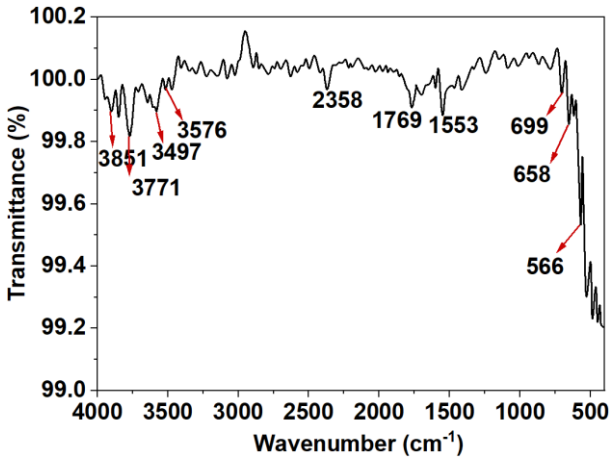

Figure 4. Analysis of FTIR spectrum of specimen S5.

Figure 4's peak at 699 cm^{-1} indicates the occurrence of the Carbon-Bromine stretches. The presence of C=C is indicated by the peaks at 1553 cm^{-1}. There is no stretching of the O-H bond since the spectra shows a peak at 1769 cm^{-1}. Among these are carbonyl compounds such ketones, esters, aldehydes, and carboxyl. Based on these findings, it seems that biocomposites degradation occurs mostly via amide pyrolysis, which in turn evolves cyclic monomers and random chain cleavage. It is possible to produce 5-hexenamide by pyrolyzing compounds that contain nearby amide groups. The absorbing groups at 2358 cm^{-1} (NH component), 3576 cm^{-1} (H-bonded hydroxy stretch, hydroxyl group,), and 3771 cm^{-1} (NH stretch) could be produced by this chemical [29]. Furthermore, when the amide group reacts with water stuck in the epoxy at high temperatures [30], the aliphatic primary amine, SH stretch, may be seen in Fourier transform infrared spectra with a wavelength greater than 3851 cm^{-1}.

CONCLUSIONS

This study investigated the mechanical characteristics of natural fiber hybridized composites, alkaline processing, and the extraction of BF, SiC, and KF natural fibers. Specimen S5 has a modulus value of 11.8 GPa and a tensile strength of 345.85 MPa. Specimen S5's flexural strength is now 107.89 MPa, the largest value recorded. S5 specimens have a high compression strength of 3109 N. S5, the composite specimen, has achieved an impact strength of 39.53 J/m^2. Specimen S5 has achieved a maximum hardness strength of 99.14. The morphological results show that the hybrid composites have an adequate amount of NF mixed with the synthetic resin. Microscopic examination also reveals consistent blend-in with three-fiber reinforcing polyester composites. These composites have an extensive range of possible applications, like industrial packaging, lightweight automotive components (car interiors), anchoring small vessels in the transportation business, and interior design in the construction arena.

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