Advances in Polymer Technology

Processing and Properties of Advanced Fiber Reinforced Polymer Matrix Composites

Lead Guest Editor: M Ravichandran
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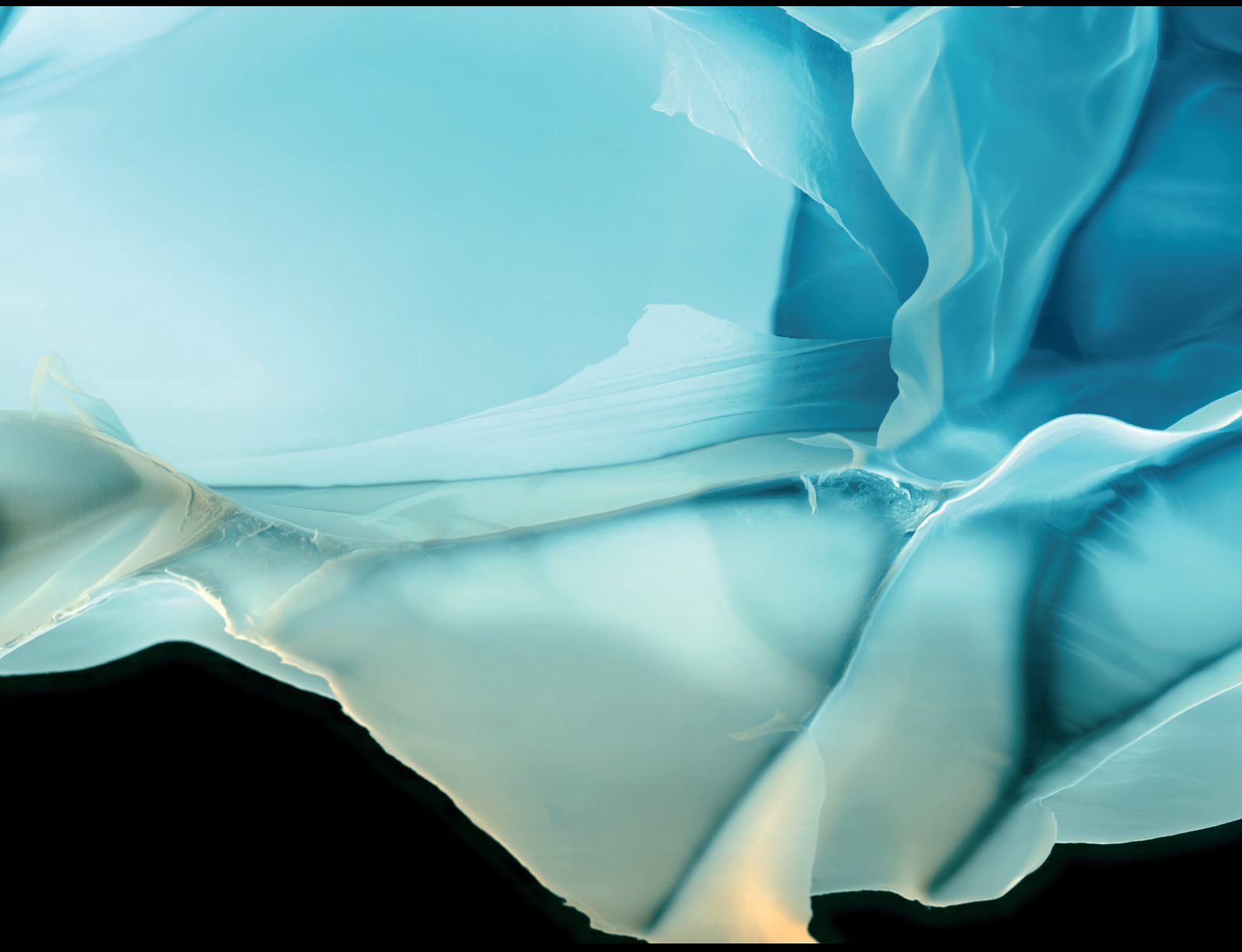

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Research Article

Mechanical Evaluation on Carbon/Basalt Fiber-Reinforced Hybrid Polymer Matrix Composite

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This work is about making hybrid composite materials out of carbon fiber mats and basalt fiber mats that are 40% reinforced with a 60% epoxy polymer matrix. Traditional hand layup has been used for the fabrication process to make five laminates of these two fibers. The mechanical properties of the hybrid composite were evaluated by measuring its tensile strength, flexural strength, impact energy, and hardness. The results showed that adding more carbon fiber layers to the composite made a big difference in its mechanical properties. In sample A, the tensile strength is 280 MPa, the flexural strength is 247 MPa, and the basalt fiber can keep more impact energy of 24 J in sample E, along with the carbon fiber and epoxy matrix. A scanning electron microscope was used to figure out how carbon/basalt fiber composite laminates break down.

1. Introduction

Natural origins for carbon strands include PAN (polyacrylonitrile), rayon, and pitches, with the last two being mostly used for low modulus filaments. The expressions "carbon" and "graphite" filaments are ordinarily utilized reciprocally, even though graphite indicates to fibers that are more noteworthy than 99% carbon piece, versus 93-95 percent for PAN-based carbon strands [1]. Carbon fiber offers the most noteworthy quality and firmness of all the strengthening fibers. Carbon fibers are particularly well-suited to high-temperature processing [2]. The significant downside to PAN-based fibers is their high relative cost, which is a consequence of the expense of the base material and an energy-intensified manufacturing process. Carbon fiber composites are more fragile than glass or aramid [3]. Carbon fibers can cause galvanic erosion when utilized alongside metals. Basalt fibers are biobased fibers made from basalt rocks that have superior physical and mechanical qualities over glass fibers [4, 5]. Basalt fiber-reinforced polymer composites have a long history of use in a variety of engineering sectors, including aerospace. The major materials for blades

have been noncrumple fabric-based fiber-reinforced composite materials with glass and carbon fibers [6]. Sustainable composites made of naturally sourced fibers like basalt, on the other hand, are being developed to lessen the environmental effects. Basalt fibers are made without the use of chemical condiments, diluters, or destructive elements, and they are recyclable [7]. Reinforcing mats and nonwoven covering are typically portrayed by weight-per-unit-of-region. The type of reinforcement, the fiber scattering, and the measure of binder that is utilized to hold the mass or cover together directly contrast between mass items. For example, in certain procedures, hand lay-up, the folio needs to break up. In different procedures, especially in pressure embellishment and pultrusion, the fastener must withstand the water-powered powers and the dissolving activity of the matrix resin during molding. Mechanical testing is a lot simpler to be controlled; more data and information can be acquired and advantageous for the clarification contrasted and the nondestructive testing [8]. Testing machines are utilized to grow better data on known materials or to grow new materials and maintain the nature of the materials. For material providers, the mechanical properties tried by these machines are a significant proportion of item quality, and testing is required for verification. In an expansive sense, quality indicates the capacity of a structure to oppose loads without mistake [9]. Tensile properties incorporate the opposition of materials to pulling or extending powers. The two most regular small-scale hardness strategies are Vickers and Knoop hardness tests. For increasingly precise and reproducible outcomes, small-scale hardness testing needs to represent impacts of test size, planning, and condition. Samples must fit in the sample stage and be opposite to the indenter tip [10]. An amazingly rough surface may decrease the precision of space information; a validated technique for cleaning tests is prescribed. The small-scale hardness analyzer should be segregated from vibrations. Statistical information is required for tests with various stages or variations in grain sizes [11]. The mechanical properties of hybrid fiber-strengthened polymer composite utilizing hybridization. Hybrid composite materials usage has been increased due to their unique mechanical and thermal properties for traditional to current material applications. To diminish the major usage of a synthetic fiber composite for different lightweight applications, synthetic/natural fiber reinforcement hybridization can enhance the usage without changing material strength. Fiber-reinforced polymer (FRP) composite has plenty of favorable circumstances, for example, high quality, low thickness, and simple handling [12]. Plain woven basalt/polyester composites made with compression molding and aged for 24 hours in normal water and seawater showed a similar weight growth of about 2% in both mediums. Following an immersion time of approximately 100 days at 80°C in distilled water, plain woven basalt/epoxy composites made employing vacuum-assisted resin infusion with a vacuum bag revealed a weight growth of around 3.5 percent. Under the same conditions, the weight gain for plain woven E-glass/epoxy composites was around 6% [13]. The blend of support, for example, glass fiber and jute fiber in composite covers, improves the mechanical quality, and this clears a path to the expansion of the usage of characteristic fibers in different applications [14].

The above works were used to select the materials of carbon/basalt fibers as reinforcement; a thermosetting epoxy polymer as matrix and hand layup technique was used to fabricate the composite and to evaluate the mechanical strength on varying carbon and basalt fiber layers; also, surface morphology of composite laminates has been conducted through SEM analysis.

2. Materials and Experimental Method

Reinforcement materials are carbon fiber mat and basalt fiber mat were supplied by SM composites, Chennai, India. Polymers comprised of long chains of molecules bound together by carbon atoms provide the basis for carbon fibers, which have the potential to be used in their replacement. The matrix particle is a combination ratio 10 : 1 of Biphenyl-F type LY556 Epoxy polymer with Araldite HY 951 hardener for improved natural fiber bonding capabilities supplied by Go green Pvt. Lmt. Chennai, India. The physical properties of materials used in this work was given in Table 1.

Overlay tests were created by the hand layup method in a shape and relieved under light tension at room temperature for 48 hr. It is possible to use hand lay-up to make a broad range of composites goods, from tiny to huge. All the covers were made with a sum of six layers; each layer of carbon fiber mat and basalt fiber mat is 15 g and by fluctuating the number and position of carbon and basalt layers to acquire five diverse loading arrangements [15]. Epoxy matrix is constant for all five samples, and reinforcement of carbon/basalt weight fractions are varied 75/15, 60/30, 45/45, 30/60, and 15/75 grams to fabricate the composite laminates and to conduct the mechanical experiments. There is no specific order to the fibers. The weight ratio of the carbon/basalt hybrid composite is given in Table 2.

2.1. Testing of Hybrid Composite. The mechanical testing of tensile test, flexural test, impact test, and hardness test to identify the mechanical properties of carbon/basalt fibers composite materials are conducted on the developed composite laminates. The tensile specimen is created from hybrid composites that have been developed. The sample was cut according to ASTM D638 specifications, and the tensile load was applied to each specimen while it was fixed between the jaws of the UTM. During the test, the results were written down [16]. The hybrid polymer matrix composite specimen for flexural investigation was prepared according to the ASTM D790 standard, with five samples are two reinforcing material compositions. The prepared specimen was placed on top of the FIE UTM clamp and bending load is applied to the specimen in a three-point bend test [17]. The Charpy impact test ASTM D256 V-notch test standardized high strain rates and the amount of energy absorbed by the material during a fracture [18]. This absorbed energy is a notch strength and stiffness measurement that may be used to look into the ductile-brittle nature of abrupt shocks. The indentation resistance of elastomeric soft plastic materials was determined using the penetration

Table 1: The physical properties of materials.

Properties	Carbon fiber	Basalt fiber	Epoxy resin
Young's modulus (GPa)	240	65	3.5
Tensile strength (MPa)	140	90	83
Density (g/cm^3)	1.67	1.7	1.15
Type	Mat form	Mat form	Clear liquid
Elongation (%)	1.59	1.3	4.3
GSM	200	200	—

Table 2: The weight ratio of carbon/basalt hybrid composite.

Sample	Weight of carbon fiber mat in g	Weight of basalt fiber mat in g	Weight of epoxy matrix in g	Weight of composite laminate in g
A	75	15	130	220
B	60	30	130	220
C	45	45	130	220
D	30	60	130	220
E	15	75	130	220

depth of a conical indent. The Shore A durometer was used to determine the hardness of rubber materials, whereas a Shore D durometer was used to determine the hardness of composites as per the ASTM D2240 standard of this hybrid composite [8].

3. Results and Discussion

The mechanical properties of tensile strength, flexural strength, impact energy, and hardness were conducted for this carbon/basalt hybrid epoxy matrix composite, and the results are taken for analyzing the mechanical stability of the hybrid composite.

3.1. Tensile Strength. The fabricated composite made of carbon/basalt fiber-reinforced epoxy-based hybrid composite laminates conducted the tensile strength test, and the results are plotted in Figure 1. The results revealed that carbon fiber and basalt fiber significantly improved the tensile strength, and these two fibers are bonding with an epoxy matrix is more significant. The results are observed, and sample A was given more tensile strength of 280 MPa; sample A contains high carbon fiber loading of 75 g and 15 g basalt fiber mat, and similar results are observed in the other four samples due to the presence of carbon fiber loading which can observe and retain its stable condition during the gradual axial loading condition.

The least tensile strength is observed in sample E contains more basalt fiber loading is 112 MPa, and the results are based on tensile loading which can show that the stress transfer between the fibers and matrix are evenly distributed which is more mechanical stability compared to basalt fiber loading. Another research also revealed a similar path for tensile strength of carbon/kenaf fiber-reinforced hybrid composite improved tensile strength of 249 MPa due to

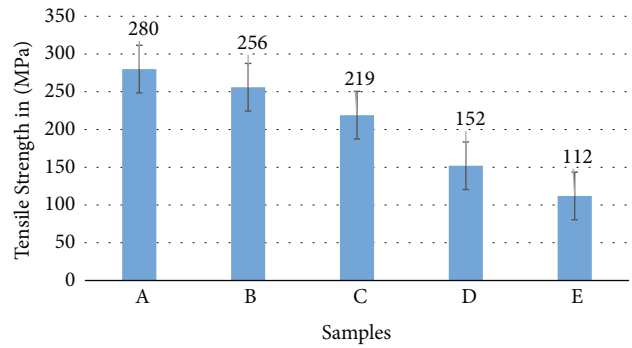

Figure 1: Tensile strength of carbon/basalt fiber hybrid epoxy composite.

more carbon fiber loading in composite and can withstand tension loading; carbon fibers are normally having higher mechanical strength compared to other synthetic fiber [19]. Therefore, a positive influence of composite laminates was observed when increasing carbon fiber loading into the composite.

3.2. Flexural Strength. The carbon/basalt fiber composite flexural results can show the same as tensile strength results, the flexural strength results revealed the maximum value observed in sample A, and the least value is observed in sample E; applying the bending load during this flexural test also can withstand more loading in carbon fiber compared to basalt fibers. The flexural strength of the hybrid composite is plotted in Figure 2.

The linear variation in carbon and basalt fiber can improve the stability during this bending load, and in sample A, it is 247 MPa flexural strength, and in sample E, it is 97 MPa; the variation between these two samples is very high. In the comparison of basalt fiber with kenaf fiber, basalt fiber can improve the mechanical stability due to the less variation in stress distribution, and the results based on gradual loading can absorb 38% more in basalt fiber compared to kenaf fiber and at the same time 40% more in carbon fiber [20] compared to basalt fiber loading into the hybrid composite. This shows that the basalt fibers acting as cladding inhibited the carbon fiber's characteristics.

3.3. Impact Energy Absorption. The Charpy impact test is performed on the hybrid composite to determine the impact energy absorption capability of the hybrid composite as a function of fiber weight fraction. The graphical results of impact energy absorption for carbon/basalt hybrid composite laminates are shown in Figure 3.

The results from the Charpy impact test reveal that basalt fiber can resist sudden force more compared to carbon fiber, and particles are strongly bonded with each other in carbon fiber; however, in basalt fiber, it has more impact resistant; therefore, when increasing basalt fiber loading, it consequently improves the impact energy absorption in results. A similar work was carried out with the development of kevlar/carbon fiber-reinforced hybrid composite, and the results show kevlar fiber is resistant to a more sudden load average of 15% compared to carbon fiber loading in

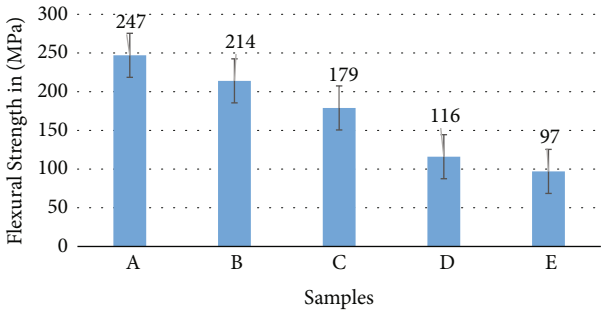

Figure 2: Flexural strength of carbon/basalt fiber hybrid composite.

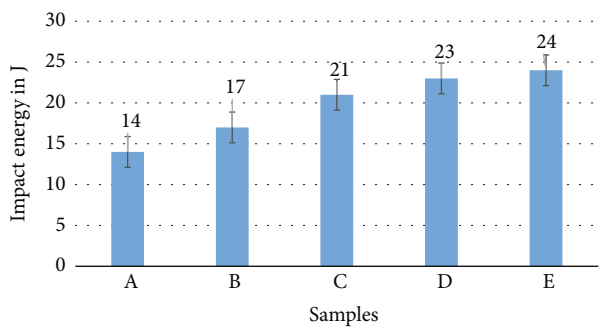

Figure 3: Impact energy of carbon/basalt fiber hybrid composite.

fabricated laminates [21]. In sample E, it was given maximum impact energy of 24 J, and in a sample A, it is 14 J, and the increasing of carbon fiber mat layer consequently reduces the impact energy absorption in this hybrid composite laminates.

3.4. Shore D Hardness of Hybrid Composite. Shore D hardness test ASTM D2240 are carried out on the fabricated composite laminates, and the graphical results are shown in Figure 4. The hardness of composite materials is majorly based on the outer surface of the laminates due to the impression on the hybrid composite, and at the same time, bonding between the carbon and basalt fibers with an epoxy matrix is quite well, and the delamination is less in this hybrid composite during this experiment. The maximum hardness capacity was observed in sample C is 74, which contains an equal amount of carbon, and basalt fibers are reinforced with epoxy matrix. The outer layer of carbon can resist more the impression during this test compared to the outer layer of basalt fiber presents in composite laminates shown in samples D and E are 68 and 70 evident of hybrid composite.

A similar test was done for sisal/carbon fiber hybrid composite which also shows the same mode of results; the outer layer of carbon fiber can resist 3% more gradual impression on the hybrid composite [22]. Therefore, the bonding capacity of carbon/basalt fibers with an epoxy polymer is significant with less variation in all five samples of hybrid composite.

3.5. SEM Analysis of Hybrid Composite. The SEM analysis was conducted for fractured samples in tensile loading, and

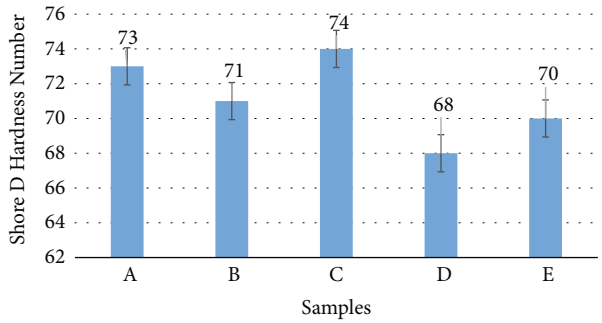

Figure 4: Shore D hardness number of carbon/basalt fiber hybrid composite.

it is evident to identify the failure mode of carbon/basalt fiber hybrid composite [23]. As seen in the SEM micrograph of the shattered surface of the hybrid composites, fiber pullouts are insignificant in the larger weight fraction of carbon fiber-reinforced hybrid composites. However, in all five samples, bonding strength with an epoxy matrix is significant and fiber pullouts and fiber cracks also minimal, and the epoxy matrix bonding with carbon fiber is a little bit more compared to basalt fiber bonding shown in the SEM output image. The SEM micrographs of carbon/basalt fiber hybrid epoxy composite are shown in Figure 5.

4. Conclusion

The developed composite is made of carbon fiber mat, basalt fiber mat is reinforced with epoxy polymer matrix, and mechanical properties of this hybrid has been evaluated; also, the SEM analysis of fracture surface has identified the mode of failure presents in this hybrid composite. The following points are the important findings of hybrid composite:

(i) The bonding capacity of this carbon/basalt with an epoxy matrix is significant, and it can suitable to fabricate the composite materials for lightweight applications

(ii) The tensile strength of this hybrid composite in sample A is 280 which is 60% more than sample E, and it reveals the positive influence of composite materials during tensile loading with increasing of the carbon fiber layer into the sequence of hybrid composite

(iii) Increasing of 7% more carbon fiber reinforcement in sample A compared to sample B can reflect the 13% more flexural strength is 247 MPa during the three-point bending analysis

(iv) The impact energy absorption is more when increasing of the basalt fiber layer in sample E is 24 J which is 41% higher impact energy compared to sample A; increasing of basalt fiber layer 35% can reflect 41% higher in results competed for 6% more energy output during this Charpy test of hybrid composite

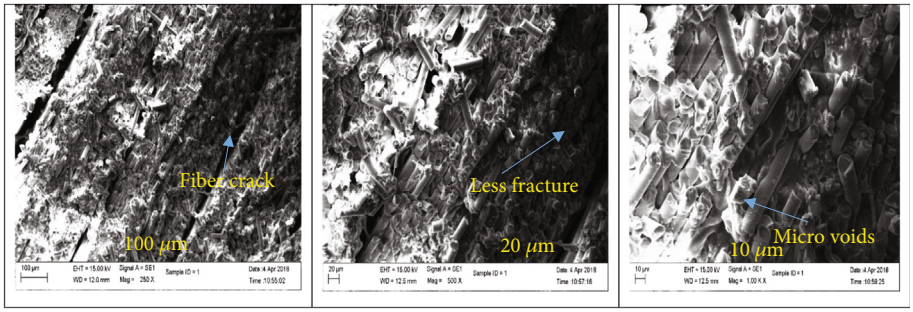

Figure 5: SEM micrographs of carbon/basalt fiber hybrid composite.

(v) The Shore D hardness capacity is also more when laminates contain the outer layer of carbon fiber, and during the SEM analysis, the fiber fracture and pullouts are very minimal as observed, and it can improve the mechanical stability of hybrid composite; also, the sample A weight fraction can be suitable for static application materials with gradual loading condition

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Mechanical Properties of Epoxy Composite Using Papaya Slice Biochar and Areca Nut Chopped Fibre

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In this work, the effects of amino silane-grafted areca fibre and papaya slice biochar particle on the mechanical, thermal conductivity, and dielectric properties of epoxy resin biocomposite were shown. The goal of the study was to find out how the way fibres are treated affects their properties and how those properties affect the composite as a whole. The acid hydrolysis process is used to treat the raw chopped fibre and slice-dried particles with amino silane and then air-dry them in an oven. The oven-dried areca nut fibre and charcoal particles are then used with a hand-layup method to make composites that meet ASTM standards. According to the results, the tensile and flexural strengths got better by 64% and 50%, respectively, and the impact resistance got better by 93%. The use of reinforcing materials gradually improved the dielectric properties and the way heat moved through the material.

1. Introduction

The reinforcement of composites in natural fibres exhibits more beneficial in composite characteristics and improving in characteristics, similarly more heat dissipation with high mechanical strength material [1]. Hybrid biobased composites that exploit the collaboration between natural fibres in a nanoreinforced in a nanosupported biobased polymer can prompt superior properties alongside keeping up with natural allure. Because of their biocompatibility, biocomposites are employed in a variety of restorative uses like domestic sector and circuit boards [2]. Typically, composites are strengthened by changing the matrix phase by adding fibre and particle, either treated or untreated, to increase the overall strength of the composite [3]. They [4] explore woven natural fibre composites, focusing on woven designs, chemical manipulation, and the underlying theory. The authors concluded that woven banana/kenaf fibres and their composites outperform woven banana/kenaf fibres and their composites in terms of mechanical and other load-bearing properties. Furthermore, [5] discovered that untreated natural areca nut fibre in biocomposites is best suited for structural and nonstructural applications due to its high load-bearing ability. This work [6] conducted a study employing areca nut husk fibre to create a biocomposite panel for a specific use. According to the authors, adding areca fibre between two glass fibres improved the composite's tensile, flexural, and time-dependent behaviour. Natural fibres, on the other hand, have been shown in multiple studies to have inferior thermal characteristics due to the presence of cellulose and loose lignin on their surfaces, and the applications are shown in Figure 1.

Recent researches have used hard particles or biochar-based compounds to improve the thermal characteristics of natural fibre composites. Many researchers have sought to develop new biofillers to improve matrix phases. Eggshell powder, wood apple and peanut shells, wheat and oat straw, tamarind seeds, papaya, banana, and apple slices may be used. The abrasion wear resistance behaviour of waste papaya slice (biowaste) particle into the polymer matrix was investigated by [7]. According to the authors, using papaya slice particles as a filler enhanced the wear properties of the pure epoxy material significantly. They [8] investigated the incorporation of discarded coconut shell biochar

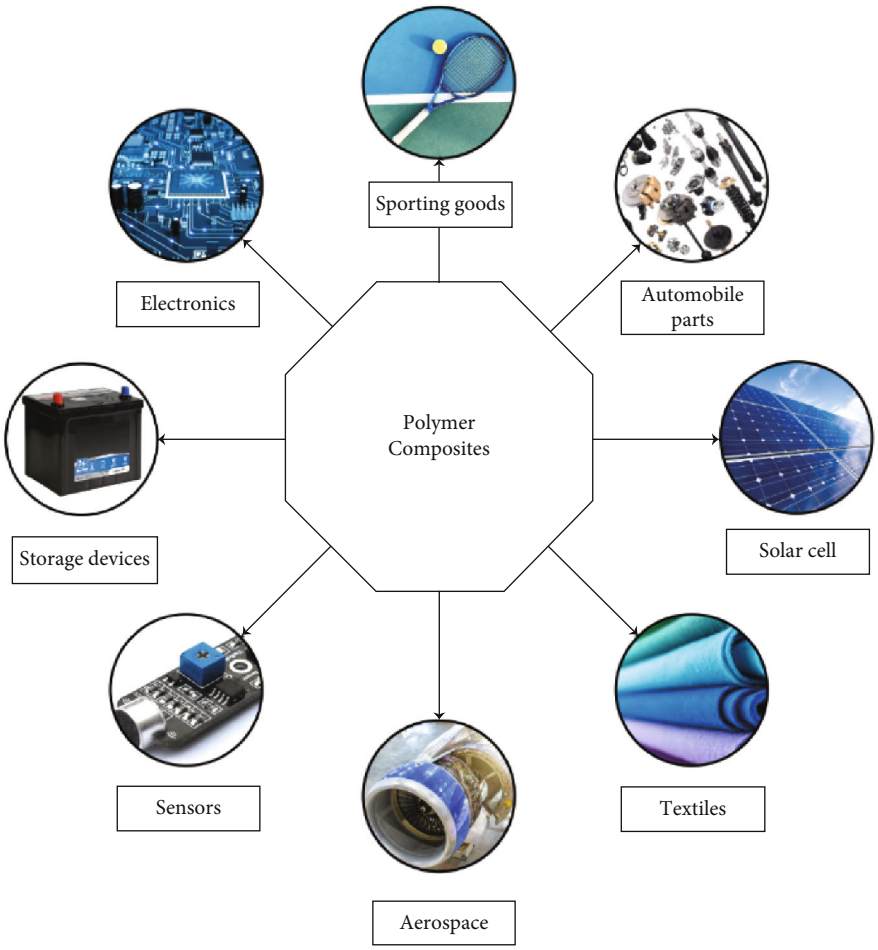

Figure 1: Application of polymer composites.

and papaya slice wastes into the resin and created composites for residential use. The SEM photos for OPB indicated a highly desirable diverse void-based structure, whereas the images for CSB revealed cylindrical fissures linked. Similarly, [9] developed an epoxy biocomposite covering for air ducts utilising biosilica. The addition of silane-treated biosilica to an epoxy matrix reduces heat conductivity while boosting viscoelastic properties, according to the author. As a result, past research suggests that particle silane surface treatment is essential for optimal performance in natural fibre composites.

As a result, it is clear that there is a significant research gap, prompting the conduct of this study, which aims to demonstrate the significant benefit of surface modification process on a novel papaya slice biochar and areca nut chopped fibre in composite preparation, as well as its significant impact on mechanical, thermal conductivity, and dielectric properties. The papaya slice is sustainable and biodegradable because it is an agriculture waste. Similarly, areca nut fibre is a long-lasting substance with a great economic value. A hand layup approach with basic process parameters and procedures could be used to produce natural fibre epoxy composites [10]. Such mechanically strengthened and impact-resistant as well as more thermally stable good dialectical characteristic composites could be employed in more cutting edge latest application [11].

2. Materials and Methodology

2.1. Materials. In this work, an epoxy resin generated from Bisphenol-A is used as the matrix, while an aliphatic curing hardener, Triethylenetetramine, is used as the curing hardener. 3-Aminopropyltrimethoxysilane (APTMS) and acetic acid were used. Metro composites in Chennai, India, provided chopped areca nut fibres as areca husks are made of a tough, fibrous substance with a length of 50 mm and a diameter of 100 m. MERCK India Ltd supplied the additional chemicals used in the silane surface treatment.

2.2. Biochar Preparation. After creating fine powders of dried papaya slice, waste papaya biochar was prepared utilising a low temperature and cycle pyrolysis procedure in this study. To make a fine particle, the dried waste papaya slices were first dried and ground for many hours. To avoid oxidation, the particles are pyrolyzed at 400 degrees Celsius in an inert environment. Figure 2 depicts the waste-to-slice powder preparation routes.

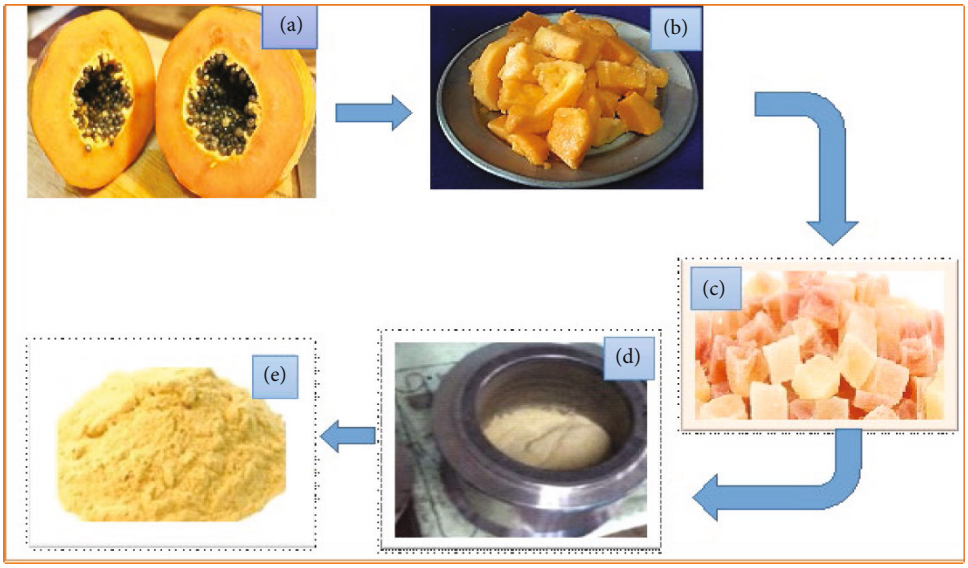

Figure 2: Papaya slice powder preparation. (a) Papaya fruit, (b) extracted slices, (c) sundried slices, (d) ball milling of papaya slice, and (e) papaya slice powder.

Fruit slices were pyrolyzed in a pyrolysis reactor with a 120 mm diameter quartz reactor heated by a muffle furnace. The papaya fruit slice was heated to 400°C at a rate of 10°C/min for 10 minutes [12, 13]. The residue that resulted was collected, sorted, and subjected to additional tests. Environmentally friendly biochar may be produced by using the ball milling procedure. Figure 3 depicts the biochar created during the current study.

2.3. Preparation of Silanized Biochar and Fibres. A suitable amount of 3-aminopropyltriethoxysilane coupling agent with varied concentration was mixed with aqueous solution for silane treatment of volume 90 percent ethanol and ten percent deionized water, followed by 5 minutes of moderate stirring. After that, the biochar was submerged in the ethanol–silane solution and steeped for 10 minutes. After that, the treated biochar was dried for 10 minutes at 110°C to eliminate moisture and produce Si–O–Si structures [14, 15].

2.4. Fabrication of Composite Laminate. A manual layup process was used to produce the composite material in the mould. The surface of the mould was lightly waxed to make composite removal easier. After thorough stirring for 30 minutes, a fine admixture was achieved using varying amounts (1, 2, and 4 vol. percent) of papaya slice biochar and chopped fibre (40 vol. percent). TETA, a curing hardener, was added to the resin-reinforcement admixture and stirred until the hardener was ready to create covalent connections with the resin chains. The admixture was then poured into the silica rubber mould and allowed to cure at room temperature before being postcured in a hot oven at 120°C for 4 hours [16, 17]. The designation and composition of manufactured composites are listed in Figure 4.

3. Characterization

The composites were tensile and flexural tested according to ASTM D-3039 and 790, respectively, with 3 samples in this study. The Izod impact test on composite was performed with a 20 J capacity machine in line with ASTM D-256. The Lee disc method was used to determine the heat conductivity of epoxy biocomposite material. A circular sample with a diameter of 11.2 cm was used to assess thermal conductivity. Similarly, an LCR HI-Tester was used to assess the dielectric constant and loss of composite material in line with ASTM D-150.

4. Results and Discussion

4.1. Mechanical Properties. Tensile testing was used to determine the tensile strength and modulus of the various volume composition composites. Figures 5(a) and 5(b) show the results of the tests for tensile strength and tensile modulus, respectively. The specimens' tensile strength and modulus for composite designation R are roughly 64 MPa and 2588 MPa, respectively, which is an extremely low figure for tensile strength and modulus [18]. The pure epoxy and lack of reinforcement in the composite designation R are due to this lower value. It demonstrates a lack of ductility and is a brittle substance. However, when we added 40 percent silane-treated areca fibre to the matrix material, a significant increase in composite designation RA was found. The results demonstrate that areca fibres have a higher load-absorbing ability than epoxy matrix during testing. The addition of 40% fibres results in a 54-percent increase in tensile strength and modulus. Further insertion of papaya slice silane-treated biochar (1 vol. percent, 2 vol. percent, and 4 vol. percent) improves tensile strength and modulus for composite designations RAB1, RAB2, and RAB3,

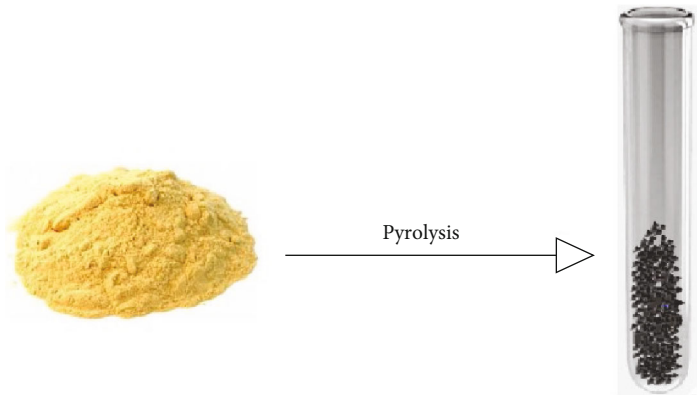

Figure 3: Biochar obtained after pyrolysis process.

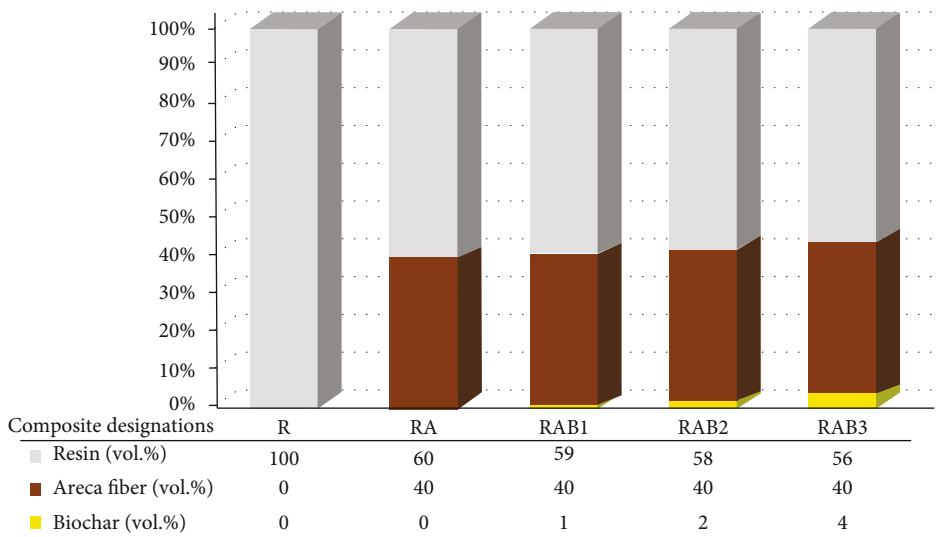

Figure 4: Material compositions for different composites.

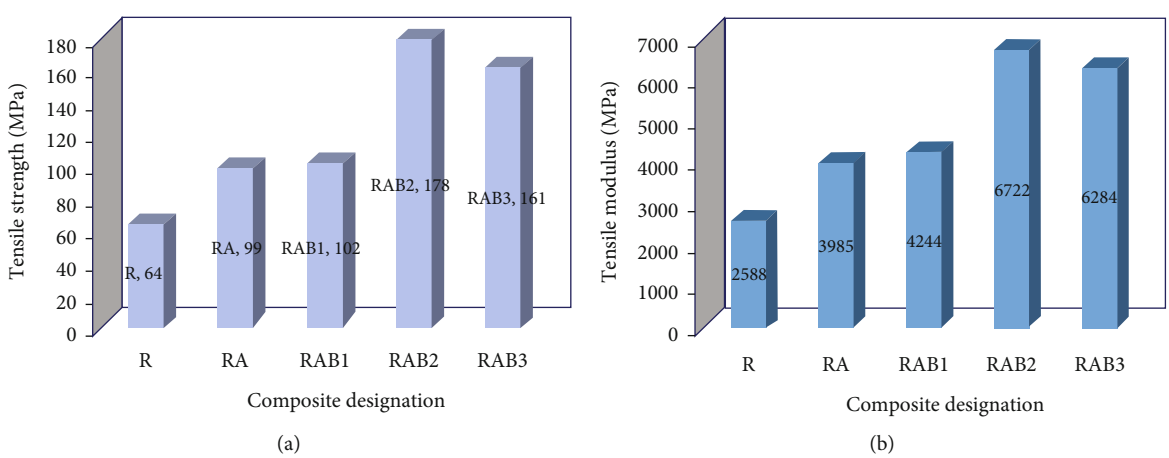

Figure 5: Tensile properties of composites.

respectively. When compared to the composite designation R [19], the increase in tensile strength and tensile modulus for RAB1 and RAB2 is roughly 60% and 64 percent for tensile strength and 60% and 61 percent for tensile modulus. Because of this, papaya slice biochar has been added to natural fibre epoxy composites. These silane-treated biochars have a maximum tensile strength and modulus of 178 MPa and 6722 MPa, respectively, and increase fibre-

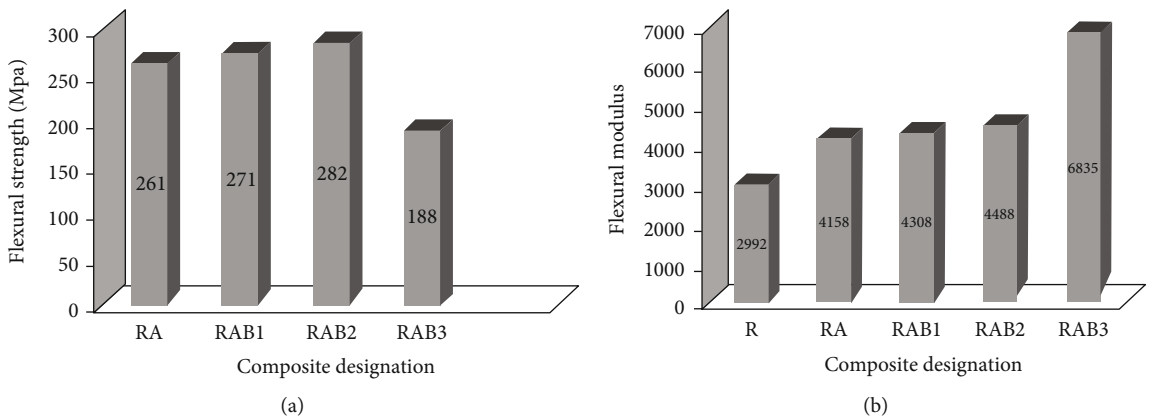

Figure 6: Flexural properties of composites.

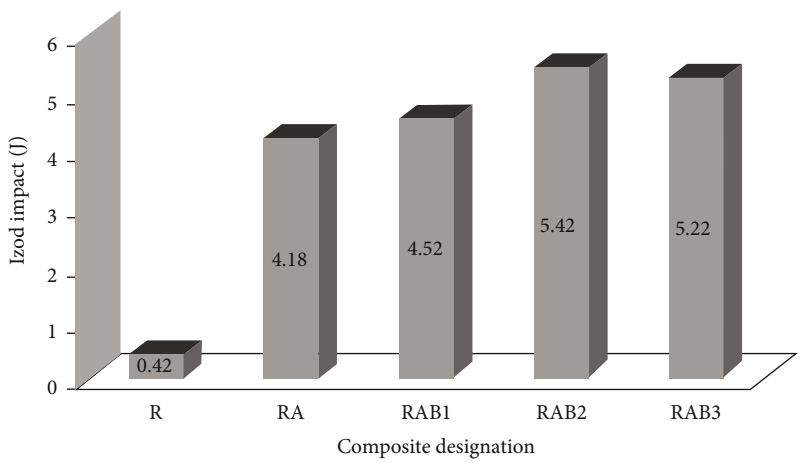

Figure 7: Izod impact of composites.

matrix adhesion. However, with the composite designation RAB3, there is a sharp decrease. It has a tensile strength of 161 MPa and a tensile modulus of 6284 MPa. It demonstrates that adding around 4% papaya slice biochar to a matrix material causes amalgamation in the matrix material, which reduces polymer bonding [20]. As a result, tensile strength and modulus are reduced.

Similarly, the addition of reinforcement boosted flexural strength and modulus, resulting in an improvement in epoxy resin's abrupt load bearing capabilities, as illustrated in Figures 6(a) and 6(b). When compared to composite designation R, the flexural strength of composite designations RA, RAB1, and RAB2 increased by 39 percent, 44 percent, and 50 percent, respectively, which yields flexural strength and modulus of just 102 MPa and 2992 MPa, respectively. Even at lower applied loads, these higher order cross linked molecular chains of epoxy cannot stretch and deform plastically when bending pressure is applied, resulting in these dismal values [21]. For strength and flexural modulus, RAB3 indicates a decrease of roughly 6835 MPa and 188 MPa, respectively. This is the result of clustering of biochar due to increment in volume fraction of papaya slice biochar in epoxy matrix natural fibre composites [22].

Figure 7 depicts an observation for impact testing. Due to the brittle nature of pure epoxy composites, it demonstrates relatively low impact resistances of roughly 0.42 J for composite designation R. However, as the amount of reinforcement, such as areca chopped fibre and papaya slice biochar, was increased, there was a noticeable improvement in impact resistance. For composites with the designations RA, RAB1, and RAB2, the increase in values is around 91 percent, 92 percent, and 93 percent, respectively. The enhanced adhesion of areca chopped fibre and papaya slice biochar with epoxy resin is attributed to the reactivity of the NH2 functional group produced through silane treatment [23]. However, impact resistance ratings for composites with the designation RAB3 have fallen to roughly 5.22 J. This is the reason of addition of 4.0 vol. % biochar in natural fibre epoxy composites which reduces the interlocking boding of epoxy by forming cluster in matrix material [24].

4.2. Thermal Conductivity. Figure 8 depicts the thermal conductivity values of reinforced epoxy composites. Composites (RA, RAB1, RAB2, and RAB3) were claimed to have improved thermal conductivity by 7%, 34%, 41%, and 47%,

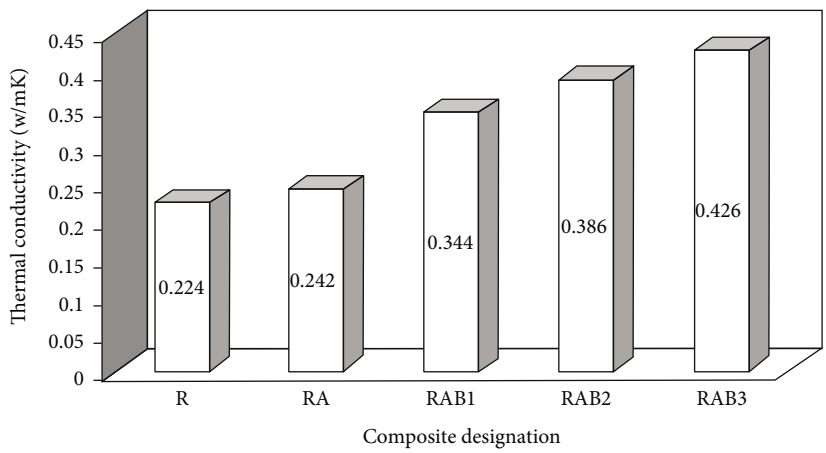

Figure 8: Thermal conductivity of composites.

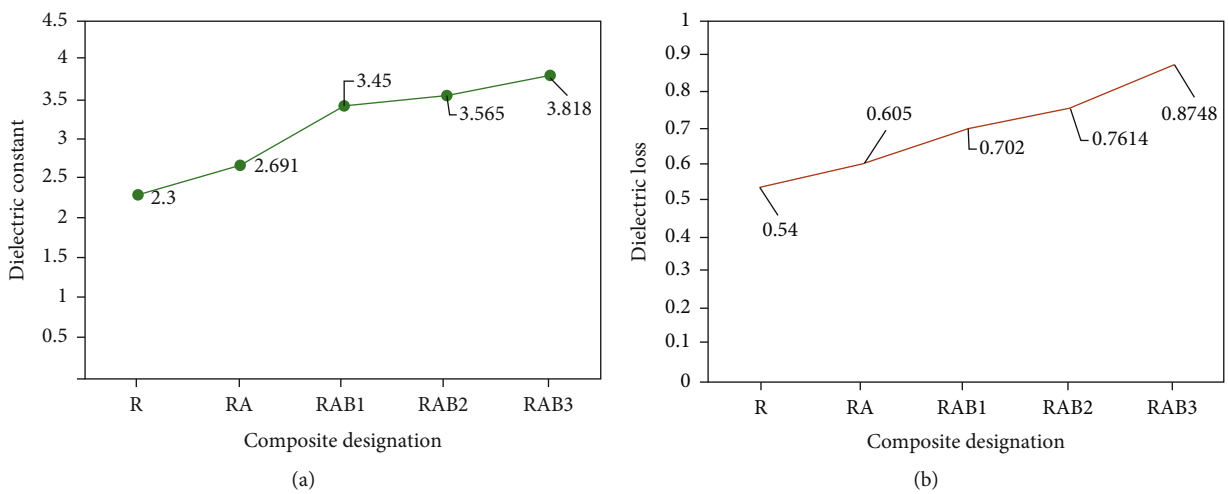

Figure 9: (a) Dielectric constant and (b) dielectric loss for different composite designation.

respectively. As the percentage of papaya slice biochar was raised, thermal conductivity rose as well. This is owing to the development of a heat-conducting biochar network in an epoxy matrix. Thermal conductivity reduces when biochar volume percent declines; this is because less biochar forms a poor network, whereas a greater volume percent impacts the rate of heat transfer by producing a better network, which enhances the epoxy matrix's heat conduction behaviour [25, 26].

4.3. Dielectric Properties. Dielectric study was performed on the epoxy matrix natural fibre composites to investigate the influence of papaya slice biochar and areca chopped fibre in epoxy resin, and the findings are displayed in Figure 9. The parallel plate capacitor approach was utilised, which entails sandwiching a dielectric material between two conductors and providing a 10 mV A.C voltage at a different frequency to each conductor. Polarization must be used to conduct the charges. According to tests, pure epoxy matrix has a dielectric constant of 2.3 and a dielectric loss of roughly 0.54. The low dielectric constant and loss are due to the epoxy molecular structure's hydrophobic properties. The mobility of electrons in any conductor causes heat due to mobility resistance; the same result was reported in the biochar distributed epoxy composite [27]. The dielectric constant and dielectric loss rise by 17 and 12 percent, respectively, when silane-treated areca chopped fibre is added. The dielectric characteristics gradually improved as more silane-treated papaya slice biochar was added. The dielectric constant is improved by 50 percent, 55 percent, and 66 percent, and the dielectric loss is improved by 30 percent, 41 percent, and 62 percent. This is due to the presence of biochar particles in the epoxy resin composite, which improves the dipole moment with respect to frequency [28].

5. Conclusions

This study uses areca chopped fibre and papaya slice biochar as reinforcing materials to create natural fibre and biochar with epoxy composites which was designed for the preparation and characterization of sustainable material

technologies. The laminates are created and characterised by hand layup, and the following conclusions are made.

(i) Mechanical testing showed a 62-percent improvement in tensile qualities and a 50-percent improvement in flexural capabilities. This improvement is due to the addition of 2% papaya slice biochar to the mix

(ii) Similarly, when the percentage of the population grows, impact resistances grow as well, peaking at roughly 5.88 J

(iii) Thermal conductivity in an epoxy matrix demonstrates an effective network that can conduct heat at 0.426 W/mk

(iv) The addition of reinforcement to the epoxy matrix boosted the dielectric characteristics gradually as well

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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Research Article

Investigation on Physical and Mechanical Properties of Abaca Fiber Composites Using Filament Winding

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Composites that were made stronger with jute fiber and glass fiber were used to test the performance of filament wound abaca fiber composites. Tensile, bending, and dynamic mechanical analyses were used to figure out the mechanical properties of the composites. Fiber composites and glass-fiber composites were found to have higher density and mechanical properties than abaca fiber-based composites. This is because resin did not get into the cell cavity of the fiber's inner tissue structure. The abaca fiber composites that worked the worst were those in which the fibers were pulled out while the fibers on the surface were torn. The fiber-reinforced epoxy circumferential composite interface junction in the twisting abaca fiber circumferential composite was found to be more flexible and have a higher glass transition temperature than any of the other composites (6000 MPa). We found that twisting abaca fiber-naval ordnance laboratory and twisting abaca fiber-prepared circumferential composite had the lowest frequency dependence and performance variability. To improve composite properties, both the outside and inside structures of twisting abaca fiber need to be fixed. There is also a rise in fiber-to-resin contact and a rise in fiber surface area. The diameter of the fibers also gets smaller.

1. Introduction

Low density, great mechanical qualities, low cost, sustainability, and biodegradability are all reasons why natural fibers are becoming increasingly popular [1]. Glass fiber [2] in composites can be replaced by natural fibers which has the potential to save energy and make it easier to process and recycle composites in an environmentally friendly way, which in turn is spurring growth in the number of products that incorporate natural fibers [3, 4]. The mechanical qualities of abaca fibers separated and manufactured from abaca are excellent [5]. At the point of break, the single-abaca fiber was capable of elongation at break of 4.3–9.7 percent. Abaca fibers are considered to be natural glass fibers because of

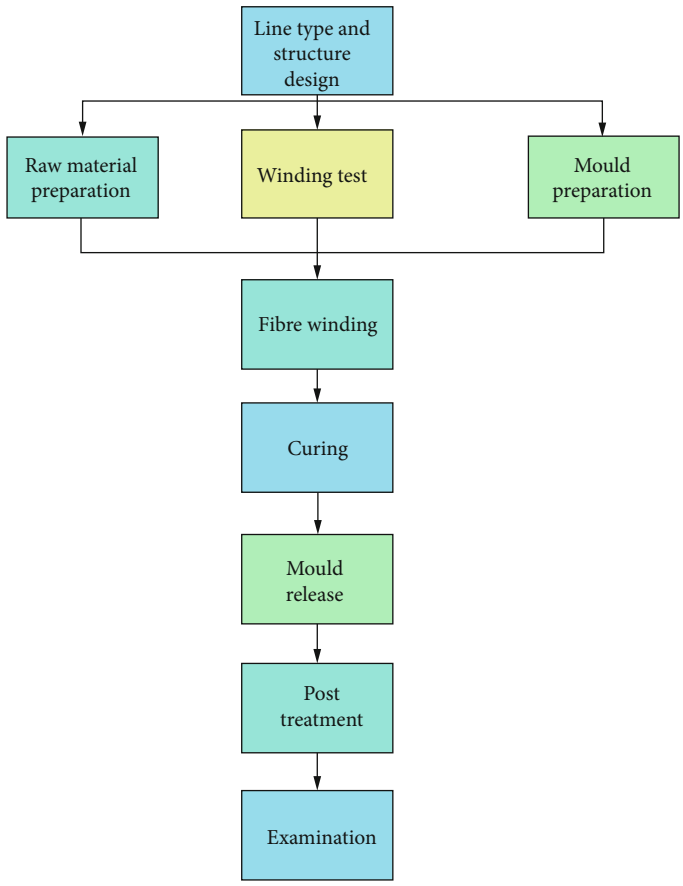


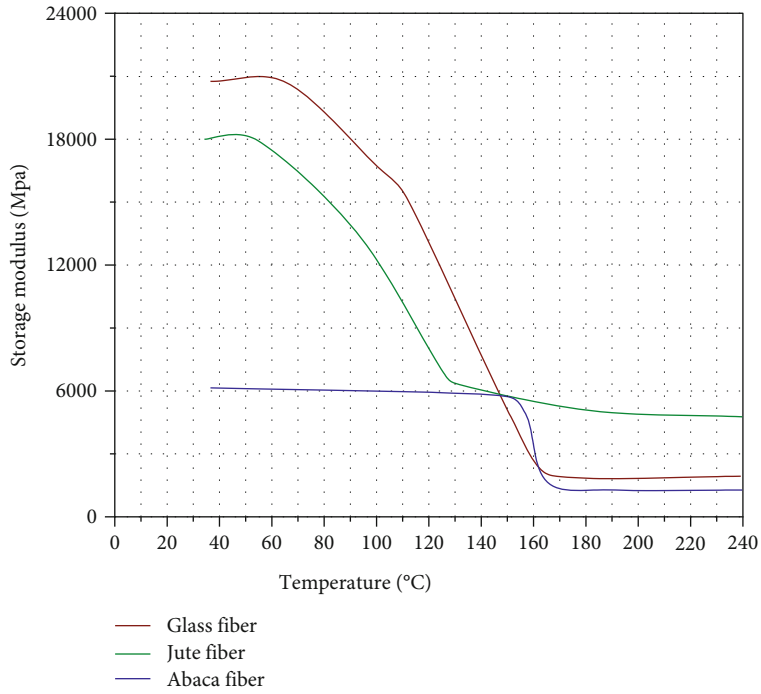
Figure 1: NOL ring fabrication preparation.

Table 1: Mechanical characteristics of composites made of different fibers.

Index	Density (g/cm^3)	Tensile strength (MPa)	Shearing strength (MPa)	Bending properties		
				Strength (MPa)	Modulus (MPa)	Surface strain (%)
TAF-NOL	0.921	46.8	Ok.9	104.61	3428.2	2.16
	0.08	4.53	1.72	11.8	327.6	0.22
JF-NOL	1.161	126.41	21.86	112.4	2162.4	8.42
	0.07	9.42	1.78	11.14	156.4	0.71
GF-NOL	1.826	875.46	38.42	832.4	12512	12.46
	0.02	13.14	0.82	29.6	161.46	0.30

their characteristics [6]. Because of its distinctive qualities and superior mechanical performance, abaca fiber has attracted a lot of attention in the fiber-reinforced composite industry [7]. Numerous studies have been done on the surface and plastic interface alterations of the abaca fiber, as well as its size and form [8]. Composites made of abaca fiber and epoxy have numerous advantages, portable, higher strength, minimal-cost, less-energy consumption, excellent buffer reliability, and nontoxicity [9].

With their regeneration and recycling capabilities, they can be used to replace glass fiber composites in numerous applications, such as automobile substructures and electrical shells as well as decorating and packaging materials [10, 11]. As the economy grows, so do the quality standards for abaca fiber composites, which are increasingly in demand [12]. The downsides of abaca fiber composites include inadequate product design, poor performance stability, and limited application in a wide range of applications because of the inherent faults of abaca and processing technology [13]. As an example of a typical plant fiber, abaca fiber is very hygroscopic and has a distinct advantage over other fiber composites in terms of application performance. To ensure the long-term viability of abaca fiber composites, new manufacturing techniques must be developed. Advanced composites can be made by winding fibers onto modules and preparing the composites using filament winding [14, 15]. Composites with good performance, stable structure, resins, different kinds and volumes of matrices, and the composite moulding method can be made using this technique.



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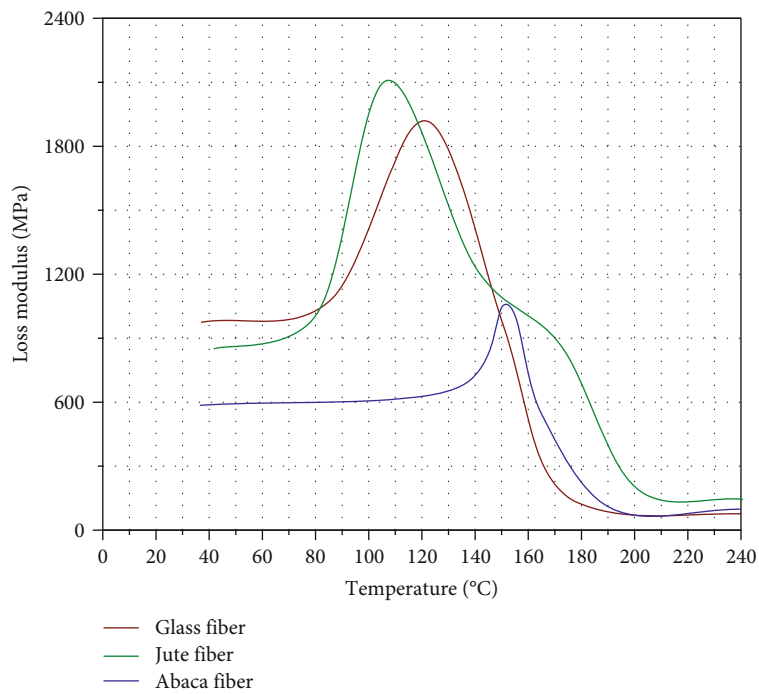

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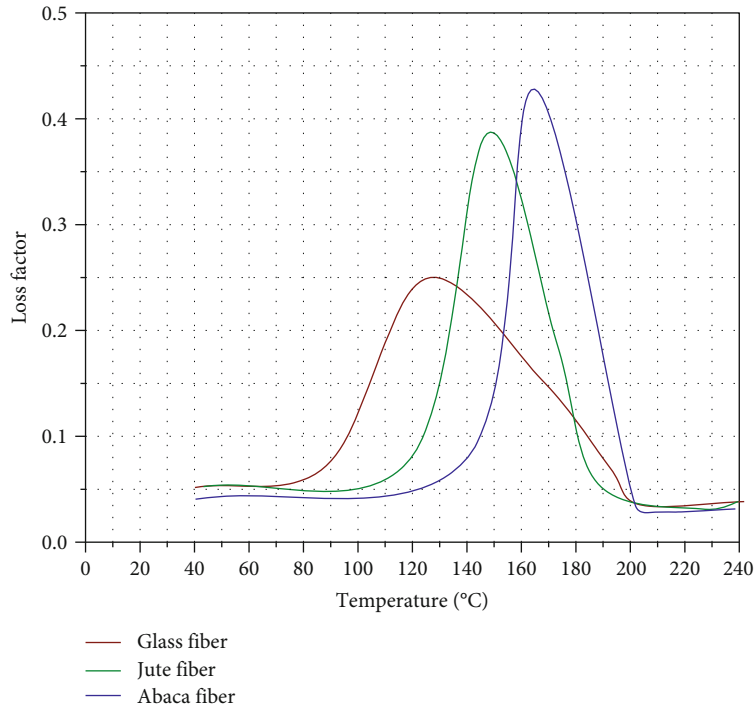


(c)

Figure 2: (a) Storage modulus. (b) Loss modulus. (c) Loss factor of circumferential composites at a single frequency.

It is advantageous to use epoxy as the matrix in abaca fiber/epoxy composites since they are extremely lightweight and strong, as well as low-cost and environmentally friendly. Automotive substructure, electrical shells, ornamentation, and packaging materials can all benefit from the replacement use of abaca fiber composites for glass composites [16]. They show the advantages of abaca fiber recycling and regeneration. As the economy improves, the demand for abaca fiber composites grows, and the quality standards become more stringent. Product design is lacking, performance is unstable, and the technology is not applicable to a wide range of markets. Abaca has various drawbacks. As an example of a typical plant fiber, abaca fiber is very hygroscopic and has a distinct advantage over other fiber composites in terms of application performance [17]. As a result, further research into the production of abaca fiber composites is required in terms of ensuring their long-term viability. Advanced composites can be made by winding fibers onto modules and preparing the composites using filament winding. Heterotypic composites with high performance, stability, and unique applications can be made using this method without the need for external force.

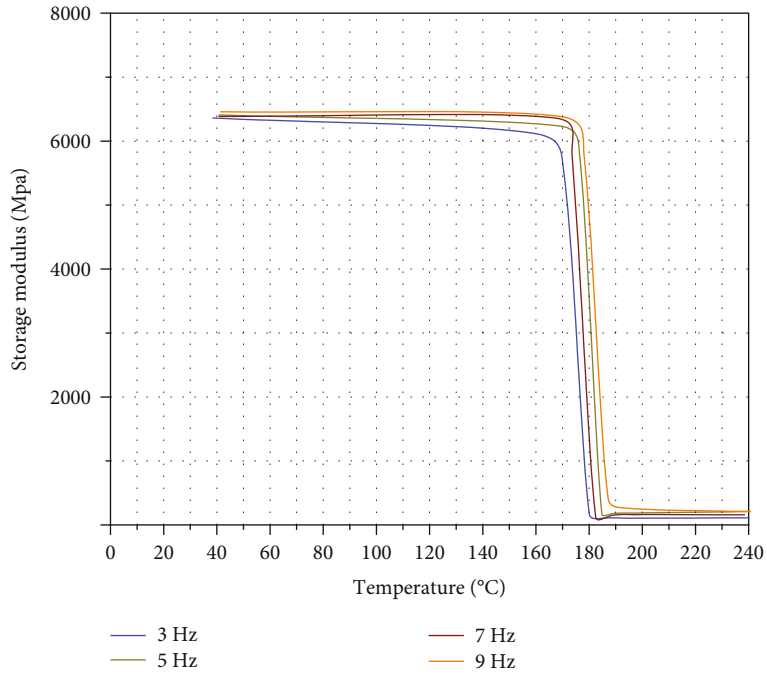
Using a hoop winding naval ordnance laboratory ring, filament winding composites' fiber characteristics and resin interface were studied. It provided fundamental winding composite process characteristics while also reflecting filament winding composites' structure and performance [18]. For the purposes of this study, the results of winding filaments of abaca fibers into the naval ordnance laboratory ring were evaluated in comparison to those of glass and jute fibers. The use of a specialised application as well as no external force is required. An approach involving both the construction of the hoop winding naval ordnance laboratory ring and winding composites requires a thorough understanding of both the fiber and resin interface properties, hence, an investigation of the product qualities was selected to provide these details [5]. To act as a guide and support for the filament winding of abaca fibers in filament winding applications, the present work first creates the twisted abaca before weaving it into the naval ordnance laboratory ring.

2. Materials and Methods

2.1. Materials. In this research, twisted abaca fiber is the strongest natural fiber available, abaca has stiffness and firmness to it. Commercially purchased jute fiber, and glass fibers were all employed in the lab. Roving density was 1080 tex for the alkali-free glass fibers.

2.2. Composite Preparation Naval Ordnance Laboratory Ring. Figure 1 shows a fabrication method for fiber-strengthened epoxy composites, such as the composite with filaments wound around a circular axis.

To make a note of the pattern and pace of the equipment's winding. First add epoxy and curing agent to the winding machine glue tank in order to reduce resin's impact on fibers then fill the mechanical tension yarn rack with dry continuous fiber and begin winding the naval ordnance laboratory ring mechanically. Remove any extra glue from the naval ordnance laboratory ring's surface with the rubber scraper while winding. Winding is complete, but do not shut down your winding machine just



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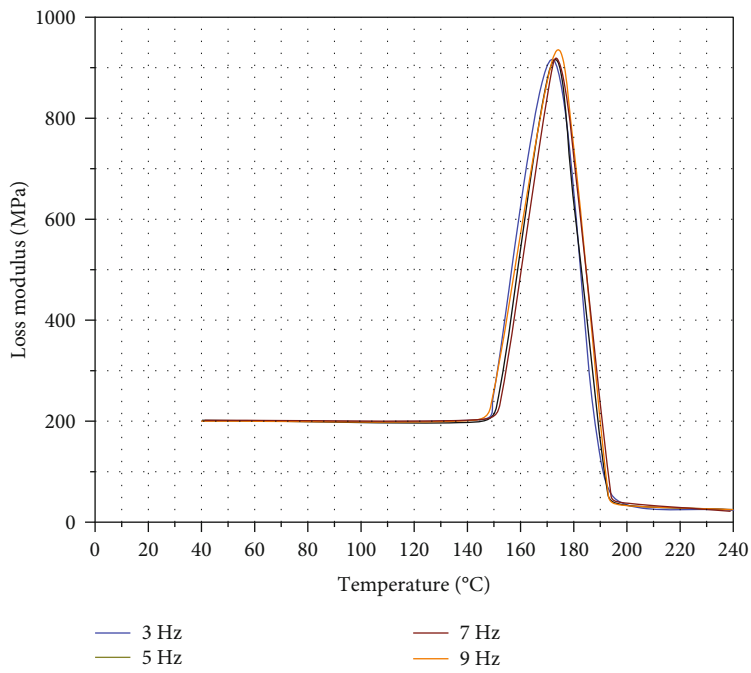

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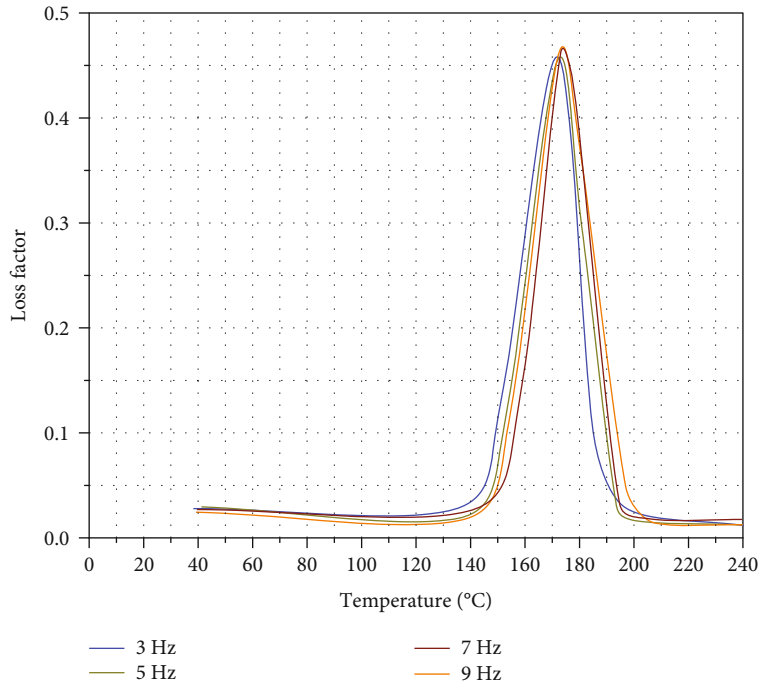

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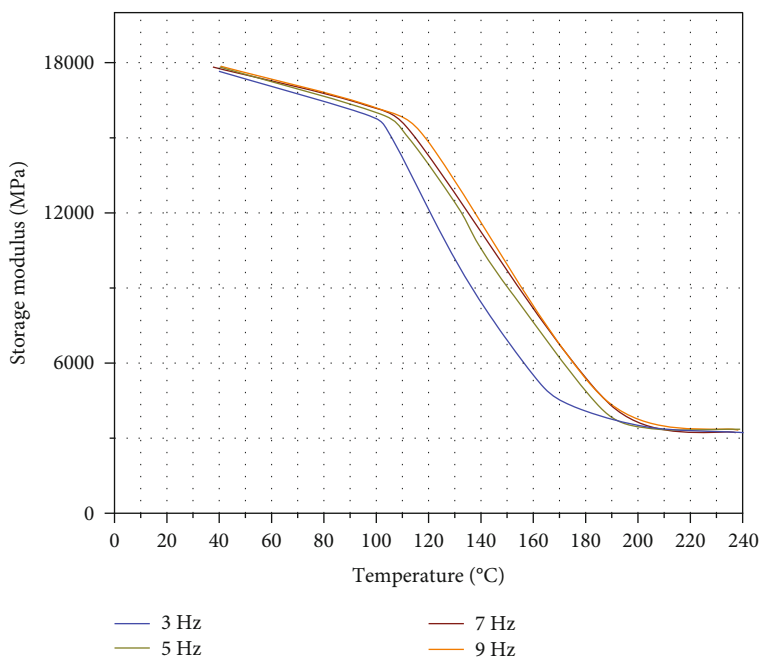

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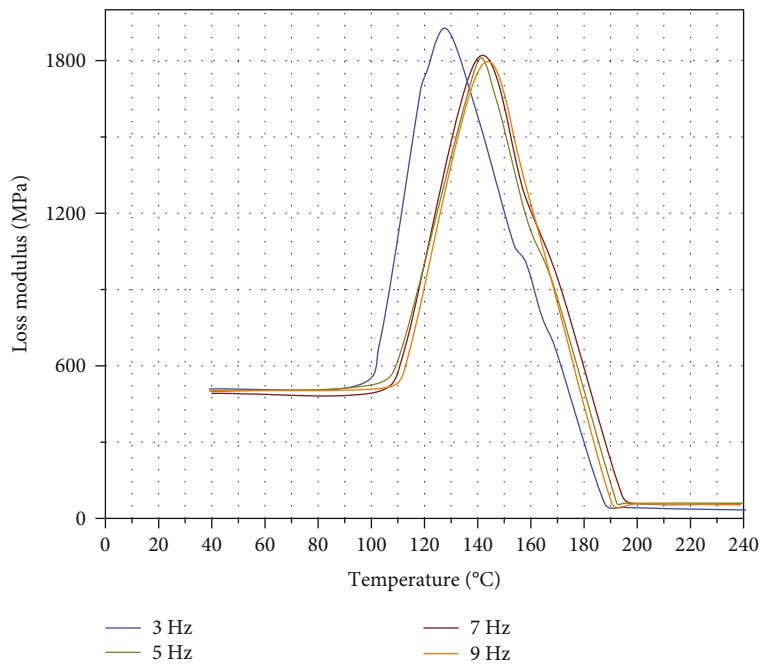

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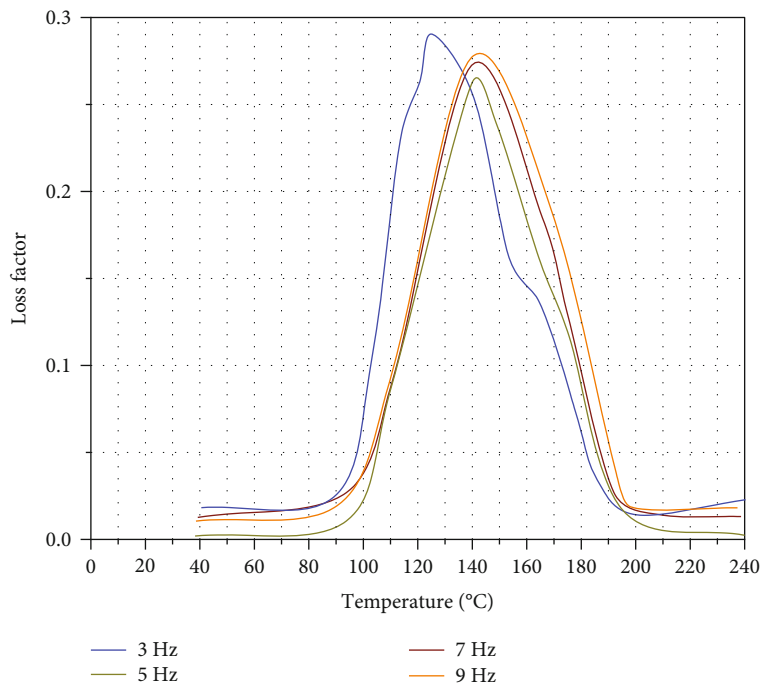

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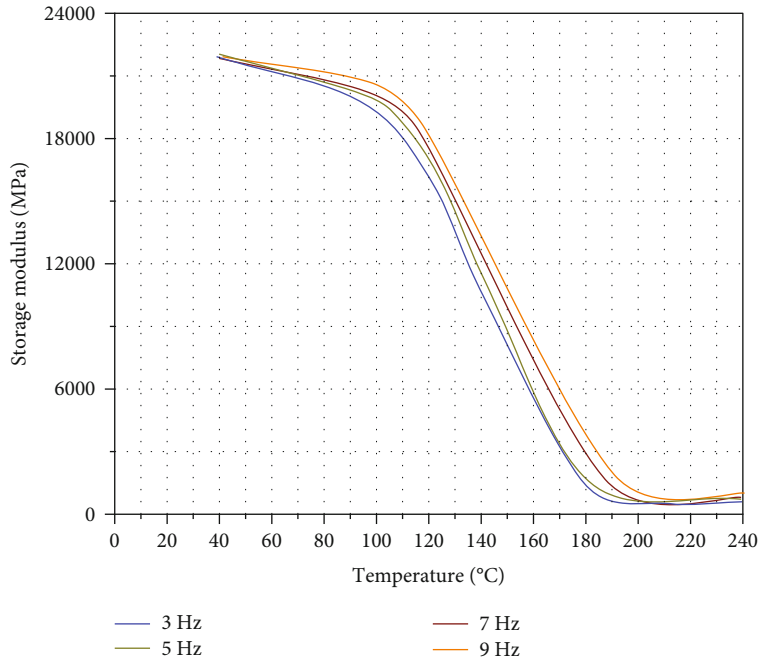

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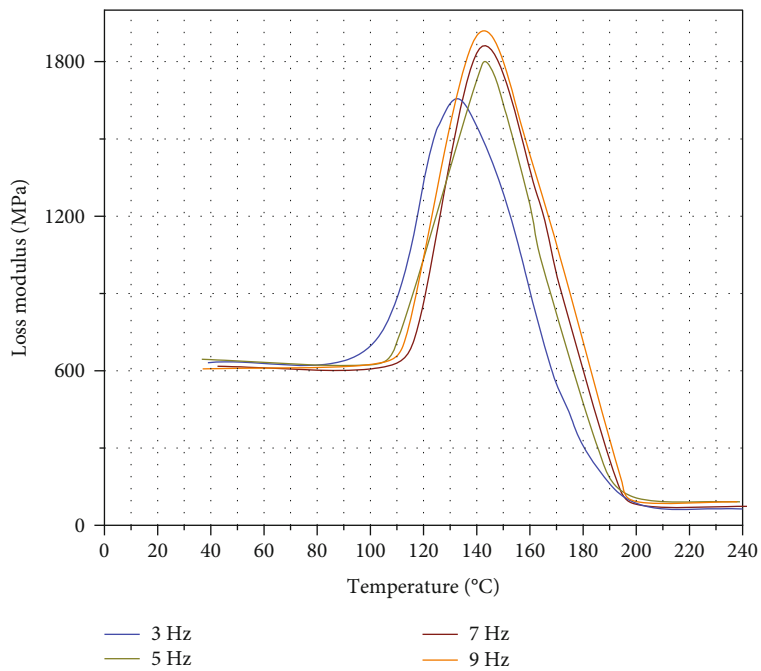

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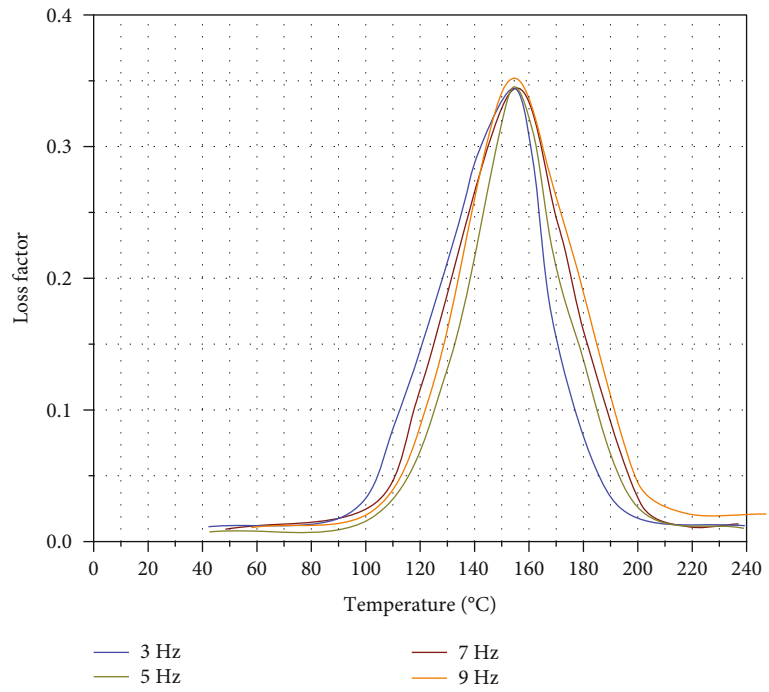


(i)

Figure 3: DMA performance data at various frequencies: (a–c) twisting abaca fiber-NOL composite; (d–f) jute fiber-NOL composite; (g–i) glass fiber-NOL composite.

Table 2: k values of NOL rings of different composites.

	k value		
	50°C	130°C	210°C
TAF-NOL	155.6	185.7	5.10
JF-NOL	360.72	2716.3	110.71
GF-NOL	249.4	831.2	15.7

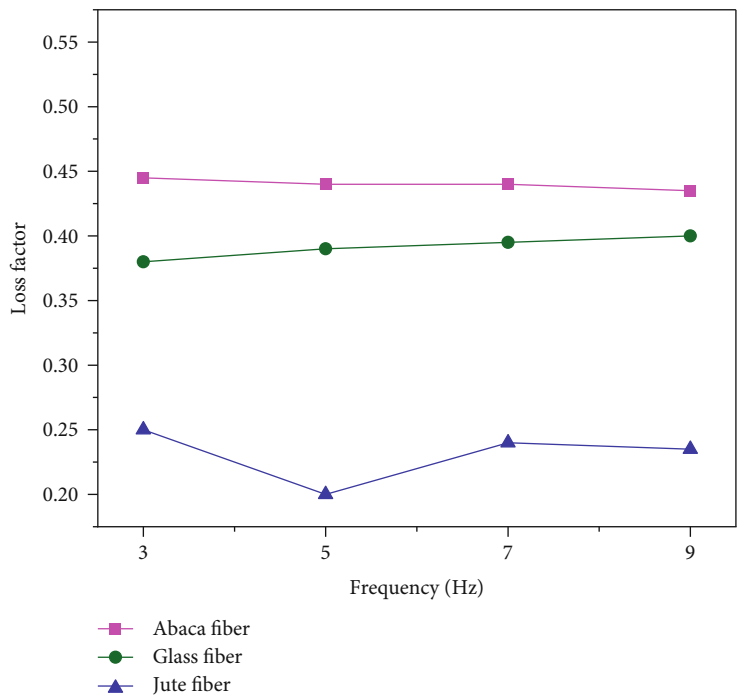
yet. Just keep the winding shaft spinning. While the online curing unit is running, the naval ordnance laboratory ring's surface temperature should be kept at 120°C for 30 minutes. Samples should be removed and postprocessed as soon as surface temperatures of the naval ordnance laboratory rings are lower than room temperature. Each of the three naval ordnance laboratory had a fiber weight content of 58 percent, 60 percent, and 62 percent. Afterward, wait at least seven days before conducting a mechanical test.

2.3. Mechanical Performance Testing. The mechanical testing machine was used to calculate the tensile properties of naval ordnance laboratory rings in accordance with ASTM D2290-19, utilising a 100 kN sensor and tensile plate fixture. Sample failure was achieved within 6090 seconds for each testing group by adjusting the loading speed. The mechanical testing machine was used to evaluate the naval ordnance laboratory rings' shear and bending characteristics in accordance with ASTM D2344/D2344M-16 and ISO 14125. As a result, the spread was four times as large for shear testing and sixteen times as large for bending testing, depending on the sample thickness. It was determined that the loading speed should be changed to ensure that all 12 samples failed within 60 to 90 seconds of being placed on the support.

2.4. Dynamic Mechanical Analysis (DMA). Using thermal dynamic mechanical analysis, we looked at how well the composite interface performed. Ananalyzer was employed to calculate the storage modulus (E'), loss modulus (E''), and loss factor (tan δ) of composite filaments in accordance with ASTM D 7028-07. Due to its lack of holding effect and its suitability for hard materials and characterization of I composites with laminated structures, the three-point bending fixture was employed in the study. At 3°C/min and amplitudes of 15 metres and frequencies of 3, 5, 7, and 9 Hz, the temperature raised to 240°C when tested in the three-point bend loading mode. Each group had three samples, and each sample was $60 \times 4 \times 3$ mm in size.

3. Results and Discussion

3.1. Mechanical Performance. Naval ordnance laboratory rings manufactured from three different fiber materials were put through their paces in order to establish their physical mechanical performance. Table 1 shows that the density of the twisting abaca fiber-NOL ring is higher than the density of the GF-NOL ring with the same winding layer and resin content (the density is 1.95 times greater). It was found that the GF-NOL composites had tensile and shear strengths 18.56, 2.49, and 7.91 times more than TAF-NOL composites, respectively. In comparison to GF-NOL and JF-NOL, the twisting abaca fiber-NOL ring



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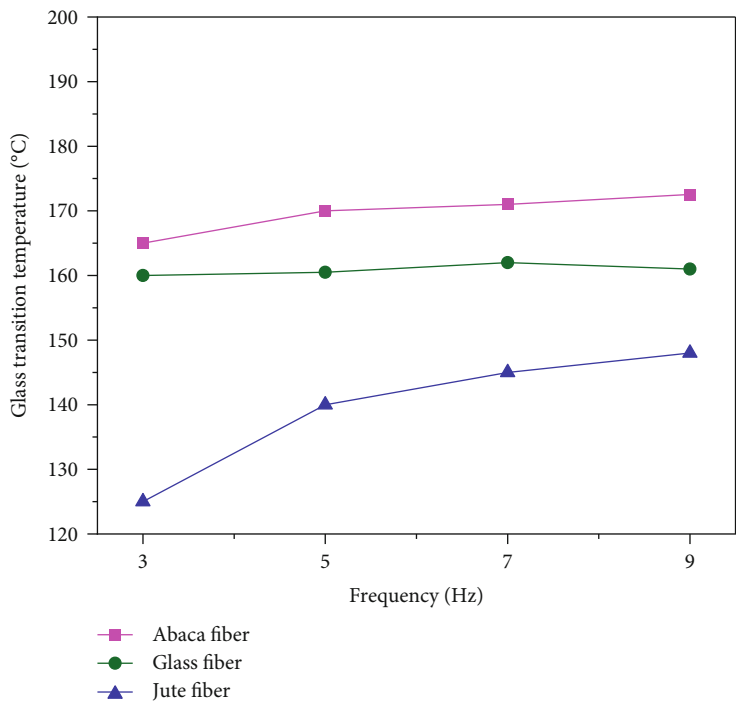

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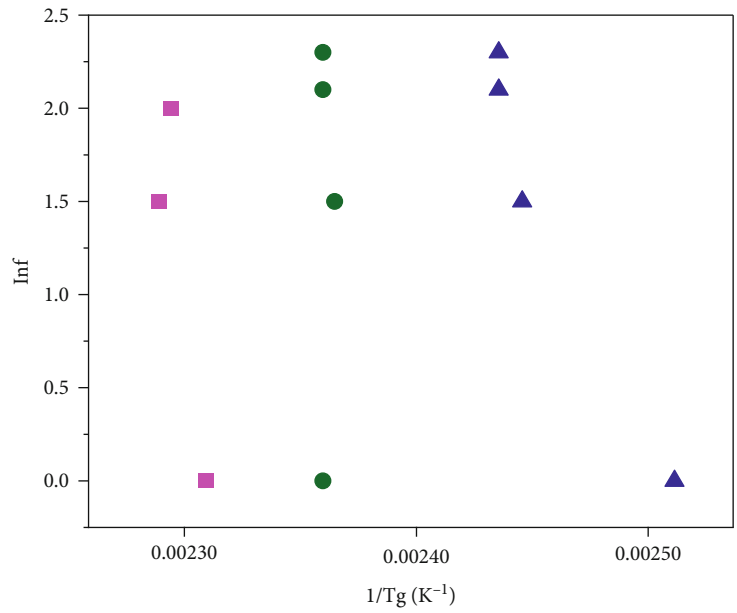

(c)

Figure 4: Circumferential composites have varying loss factors and Tg at variant frequencies. (a) Loss factor vs. frequency. (b) Tg vs. frequency. (c) Apparent activation energies of circumferential composites.

has a lesser strength. The JF-NOL GF-NOL rings have a lower surface bending strain than the JF-NOL GF-NOL rings, which indicates a higher level of stiffness.

Resin failed to penetrate the abaca fiber's interior pores because of the fiber's parenchyma and conduit structure, while the jute fiber's pores were smaller than those of the abaca fiber. As each fiber in the GF-NOL rings cross section was coated in the epoxy, the resin was well diffused around the fibers, ensuring good bonding qualities. According to [19], a fiber was encapsulated by the polymer matrix, and fibers were retrieved from the surface, dragged out, and torn. The key considerations in twisting abaca fiber preparation should not be to reduce the diameter of the twisting abaca fiber or increase its specific area or improve surface interaction between the fiber and resin.

3.2. Thermodynamic Mechanical Performance. Correlation coefficient of storage modulus frequency dependency was used to calculate the following equation's k value.

$$E' = klgf + b. \tag{1}$$

Understanding the correlation between glass transition temperatures and frequencies, this link among Tg and frequency of transition was studied by changing the Arrhenius formula and arriving at the following equation.

$$E_a = -R \cdot \frac{d(\ln f)}{d(1/T_g)}, \tag{2}$$

where Ea is the glass transition apparent activation energy (kJ/mol), R is the universal gas constant, $(8.314 \times 10^{-3}\text{kJ}/(\text{mol} \cdot \text{K})$, f is the frequency (Hz), and Tg is the glass transition temperature of the fiber composite (K) at frequency f.

Figure 2 depicts the results of dynamic mechanical tests performed at a frequency of 1 Hz on three fiber circumferential composites. This resulted in GF's, $E-'$ value being 3.53 times bigger than twisting abaca fiber's circumferential composite $E-'$ value when three fibers were employed. In order to increase the storage capacity of the epoxy matrix, the fiber-strengthened epoxy circumferential composite interface was actually linked.

GF-storage, twisting abaca fiber-NOL, and jute fiber-NOL's moduli shrank by 11.9%, 68.4%, and 75.2% when the temperature increased from 40 to 150 degrees Celsius, respectively. These decreases had no effect on the storage moduli of NOL rings produced from three fibers. Twisting abaca fiber circumferential composite storage moduli decreased very little GF, and jute fiber circumferential composite storage moduli both decreased significantly. Because of the superior fiber-resin interaction, the twisting abaca fiber composites had better thermal stability at low and medium temperatures than at high temperatures. Nearly comparable storage modulus values were found for all three materials at 148°C. At temperatures greater than 150°C, the jute fiber composite reached its maximal storage modulus. The storage modulus of all three materials decreased as a result of an increase in temperature. After temperatures escalated from 50°C to 180°C, a rapid decrease in storage modulus was seen in the twisting abaca fiber circumferential composite. Temperatures above 245°C lowered the tensile strength of the twisting abaca fiber, jute fiber, and glass fiber composites by 6.42 to 8.2 to 82.3 to 97.1 percent, respectively.

Loss modulus in the temperature range of 40–160°C was found to be higher for GF and jute fiber circumferential composites than twisting abaca fiber. The heat energy of molecular

motion produced by this movement increased the loss modulus when the molecule chains displayed greater frictional movement. Twisting abaca fiber-NOL, jute fiber-NOL, and GF-NOL loss peak areas (MPa.min) were 38900.42, 144685.46, and 127486.81 (MPa.min), respectively. As a result, the interface bonding between twisting abaca fiber-NOL and NOL was shown to be weakest. For twisting abaca fiber-NOL, the glass transition temperature was 162.36°C; for JF-NOL, the glass transition temperature was 129.5°C; and for the GF-NOL, the glass transition temperature was 162.7°C. Due to better elasticity and a wider diameter, twisting abaca fiber-loss NOL's factor was lower than that of other composites, which suggested that the twisting abaca fiber composite had a lower loss factor. Because of its greater elasticity and plasticizing capabilities, twisting abaca fiber's circumferential composite was found to have a higher glass transition temperature than any other composite.

Using different frequencies, the DMA curves of twisting abaca fiber-NOL, jute fiber-NOL, and GF-NOL are shown in Figure 3. The three circular composites were all affected in the same way by frequency. A greater frequency range resulted in greater tan δ, E'', and E'. It was because of this that the composite's molecular chains and interface held up under the load. Smaller composite changes and a bigger storage modulus were achieved as a result of an increase in frequency. Equation k determines the storage modulus-frequency correlation coefficient (1). The glassy condition was defined as a temperature between 50°C and 130°C, whereas the rubbery state was defined as a temperature of 210°C. Temperature-dependent storage modulus (k) values for the twisting abaca fiber-NOL composite and the circumferential composite made from TAF were lowest, suggesting the least frequency dependency of the storage modulus and the least performance variability. Table 2 shows k values of NOL rings of different composites.

On the graph in Figure 4, we can see the relationship between the composites' frequency and loss factor as well as their frequency and Tg. The twisting abaca fiber circumferential composites and fiber-refined composites with an increase in frequency saw a little rise in peak temperature and peak loss modulus and loss factor. The loss modulus of the JF composite decreased little as the frequency increased, while the loss factor gradually increased.

Slower relaxation times for the molecular chain sliding motion were seen in the three circumferential composites as the frequency rose. Hysteresis can be lessened or perhaps eliminated entirely by raising the temperature of the system to allow for the molecule chain to move more freely. The composite's performance changed dramatically when heated to 170°C. Polymer segment motion reactions decreased quicker than observation times, resulting in a shift in twisting abaca fiber circumferential composite's loss modulus and loss factor during the glass transition stage.

While the twisting abaca fiber composite had an activation energy of 510.6 kJ/mol, each of the GF circumferential composites possessed an activation energy of 1261.15 kJ/mol each. It was found that the twisting abaca fiber and jute fiber circumferential composite interface had better interfacial bind characteristics than the GF circumferential composite. This means that the epoxy bond among plant fiber and epoxy is stronger than that among glass fiber and epoxy. In addition, the JF circumferential composite's fiber-resin interface had the best performance because of the low number of internal pore flaws. In terms to increase the mechanical characteristics of the abaca fiber composite, it is necessary to treat and modify the internal and external structures of the fiber.

4. Conclusions

To create twisting abaca fiber-NOL, jute fiber-NOL, and GF-NOL rings, filament winding was used and the following conclusion is made below as:

(i) The resin could not permeate the interior pores of the abaca fiber, but jute fiber also had small holes, even smaller than those of the abaca fiber, in the comparison of the structures. As each fiber in the GF-NOL rings cross section was coated in the epoxy, the resin was well diffused around the fibers, ensuring good bonding qualities

(ii) Twisting abaca fiber-NOL had tensile, shear, and bending strengths that were 6.21 percent, 49.84 percent, and 13.15 percent higher than those of GF-NOL. Twisting abaca fiber and jute fiber circumferential composite had a superior interface, as shown by activation energy, than the GF circumferential composite

(iii) Among the three materials studied, twisting abaca fiber circumferential composite had the highest glass transition temperature, indicating the greatest plasticizing and elastomeric properties

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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Research Article

Dynamic Mechanical Analysis of Banyan/Ramie Fibers Reinforced with Nanoparticle Hybrid Polymer Composite

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Natural fibers are an increasing potential alternative to synthetic fibers in recent research, due to their unique properties and weight ratio in composite materials. In this work, the banyan mat and ramie mat are used as reinforcement phase and the epoxy polymer is used as matrix material, and granite nanoparticles are used as filler for making composite laminates. The two phases of reinforcing and matrix were taken at an equal ratio of 50% in each, and the conventional hand layup process was fabricated making five different sequences of laminates. In this analysis, the dynamical mechanical properties of this hybrid composite are identified with the erratic weight ratio of banyan mat and ramie mat fabrics. The results revealed the maximum storage modulus is 1580 MPa at 93.8°C and a loss modulus of 298 MPa at 93.8°C in sample A, 12% more storage modulus, 17% more loss modulus was obtained in sample A compared to sample B, and 29% E' and 27% E'' more compared to sample E and also using storage modulus, loss modulus, damping factor are the viscoelastic behavior which can reveal the glass transition temperature of hybrid composite laminates by conducting dynamic mechanical analysis, and SEM test was used to identify the failure mode of hybrid composite.

1. Introduction

Fiber has been reliably utilized in development since the beginning of the twentieth century. During the 1960s and 1970s, the utilization of fibers from asbestos diminished the consciousness of the medical issues brought about by the long-haul substantial presentation of these airborne fibers [1]. Aramid is a sweet-smelling polyimide that is a man-made natural fiber for composite reinforcement and is the most generally recognized manufactured fiber. Aramid has excellent mechanical capabilities at low thickness, as well as the added benefit of sturdiness or resistance to harm/sway. When compared to glass and carbon, they are said to have a sensible high elasticity, a medium modulus, and an unusually low thickness [2]. Unidirectional sheets are thin, and different layers are required for most auxiliary applications. Conventional applications for unidirectional reinforcement incorporate profoundly weighted strategic composites, for example, aviation machine parts or race vehicles [3]. The mechanical properties of the material under various loads applied and the conduct of auxiliary reaction of an example can be dissected and examined. Aluminum silicon carbide metal matrix composites are utilized in different

fields like aviation, airplanes, submerged cars, the substrate in hardware, golf clubs, turbine cutting edges, and brake cushions [4]. High-throughput robotized methods are these days assuming a key job in polymer composite assembling in various enterprises, for example, cars and aviation. There is a need to deliver high-volume parts effectively; computerized tape layup and mechanized fiber conditions can create composite parts proficiently, and with the approach of added substance production, the intricacy of these segments is expanding [5]. Several factors, including fiber quality, modulus, and fiber length, determine the mechanical properties of a typical fiber-strengthened composite and orientation, as well as the quality of the fiber-network interfacial bond. The developed composite was made of neem/banyan fibers that can be used to improve the dynamical behavior when increasing banyan fiber loading, and the results revealed banyan woven fabric can improve the storage modulus average of 5% compared to chopped neem fiber [6]. High mechanical characteristics of composites require a robust fiber-lattice interface connection. A good interfacial connection is necessary for successful pressure transfer from the lattice to the fiber, allowing the composite to make the most of its fiber quality. The mechanical qualities of common filaments, such as flax, hemp, jute, and sisal, are outstanding, and they may even outperform glass fibers in terms of explicit quality and modulus. The thickness of every one of the overlays and water retention properties are additionally assessed. The six covers of banana and E-glass fabrics of measurement 240 $\times 240 \times 3\ mm^3$ are created by hand layup and vacuum stowing strategy. The impregnation of the covers is finished by utilizing polyester tar as the lattice material. At last, relieving is done in the autoclave for 4 hours at 70°C [7, 8].

Dynamic mechanical properties of unidirectional banana/jute mixture fiber-fortified composites and contrast and single characteristic fiber-strengthened composites. The physical and dynamic mechanical properties of the natural fiber composites were acquired by testing the composite for thickness, tensile, flexural, between-laminar shear effect, hardness properties, and viscoelastic properties of the hybrid composite. Consolidation of the filaments into an epoxy grid brought about an expansion in mechanical properties up to 30 wt% of fiber loading. It is discovered that the hybrid composite gives empowering results when contrasting with individual fiber composites; the morphologies of the composites are likewise contemplated by the SEM process, respectively [9]. Due to hybridization and the reduction in hydrophilic nature by the surface treatment process, 10 wt percent ramie (R)/10 wt percent kenaf- (K-) based epoxy composites with 5 wt percent benzoyl chloride treatment (T) showed good mechanical properties with an ultimate tensile strength of 37.39 MPa, an ultimate flexural strength of 63.53 MPa, and impact strength of 70.36 J/m [10]. The filler substitutes fill in the gaps between the fiber and matrix phases, improving the characteristics. The use of TOPSIS for multiresponse optimization revealed that hybrid SP had the most impact on the overall tribological properties of natural fiber composites, with rank 1 being the most important, followed by filler incorporation [11]. Filler mixing improves fiber/matrix adhesion and increases mechanical characteristics. Filler addition also improved the flexural and impact characteristics by up to 22.11 percent and 21.77 percent, respectively. The application of filler powders explains the good bonding nature of the SEM data. The presence of silica and other inorganic components in the polymer composites was confirmed by EDX, which improved the characteristics [12]. The outcomes indicated the improvement of intractable and flexural properties (quality and modulus) of COIR/epoxy composites by hybridization with pineapple leaf fiber, up to 50 vol%. The crossover composites strengthened with equivalent volume substance of pineapple leaf fiber (PALF) and coconut husk fiber (coir) have the most elevated tractable flexural and sway quality. The water retention test uncovered the decrement in sorption fondness with the expansion of coir fiber content. The crossover composite (P50-C50) assimilates 62% and 32% less water than that of unadulterated PALF/epoxy and COIR/epoxy composites [13, 14]. To lift the dynamic usage of common fiber-strengthened composites in basic applications, it is incredibly required to elevate the properties of NFRC by the utilization of a hybridization device. The major outcome to conduct the dynamic analysis revealed the mechanical and viscoelastic properties of thermosetting polymers, thermoplastic polymers, and elastomers of the hybrid composite. Three basic components make up the reinforcing process in particle-filled polymers. Chemical links between polymer chains provide a material with a more rigid structure and, ultimately, a better defined shape. The first is size-independent and involves replacing a fraction of low stiffness polymers with more rigid particles. The second involves stress transfer into nonspherical particles as a result of shear stress developed at the particle-matrix interface, and the third involves chain stiffening as a result of dynamical and parking restrictions at the segment scale, which are both strongly correlated with particle size [15]. The banyan fiber contains more mechanical properties and effective life, which is used to increase the mechanical stability, and the ramie fibers are quite increased to develop composite sections for replacing the synthetic fiber materials [16]. Traditional continuum mechanics cannot be employed with polymers because of their very nonlocal deformation behavior. Instead, higher-order elasticity combined with molecular dynamics has been proposed as a feasible framework to use with amorphous materials [17]. The storage moduli curves for woven PET (PP) and interlaced PET/hemp hybrid (PH) composite specimens started to decline earlier than woven hemp (HH) and interlaced hemp (IW) PET/hemp hybrids (HP). Increasing the temperature over the setpoint Tg produces a material transition from one state to another. To change from a glassy to a rubbery state. A composite's constituents in the glassy condition are densely packed and highly concentrated, immobile, and have high intermolecular interactions that contribute to their mobility with a larger modulus of storage. As the temperature rises, the molecule mobility increases and molecular bonding relaxes, resulting in a loss of stiffness and thus a decrease in the storage modulus value. Furthermore, the maximal storage modulus of the composite is reached in the rubber zone, which appears at 100°C and above, since the epoxy resin becomes unstable, dynamical analysis can generate data to define the dynamic mechanical properties of woven and interwoven hybrid composites, which can be utilized to replace concrete, steel, and wood reinforcements in industries such as construction and automotive [18, 19].

The above literature was used to identify the objective of this study which is related to banyan and ramie fibers which are selected as reinforcement and epoxy polymer resin with hardener selected for the matrix phase and granite fine particles used by way of plaster and to construct the hybrid composite through hand layup technique and further to analyze the viscoelastic behaviors of storage modulus, loss modulus, and damping factor this natural fiber hybrid composite by dynamic mechanical analysis and identify the failure mode by conducting scanning electron microscopic experiment.

2. Materials and Methods

2.1. Materials Used. The hybrid composite laminates were developed thru banyan woven mat fabric, ramie fiber mat, and granite nanoparticles along with the epoxy polymer, banyan woven fabric, and ramie fiber mat extracted from a natural source by retting process and it was supplied by Go Green Industry Chennai, India, and the filler material of granite nanoparticles was supplied by Dacss Granite Krishnagiri, Tamil Nadu, India. The matrix material of bisphenol A diglycidyl ether and HY951 hardener was supplied by Javanthee Enterprises, Chennai, India. The general properties of the materials used in this research are given in Table 1, and the chemical properties are given in Table 2. The characteristic attribute of thermosetting polymeric epoxy polymers is cross-linking. Cross-linking is almost always irreversible, and the resulting thermosetting material will deteriorate or burn if heated. Once a substance is cross-linked, it is extremely difficult or impossible to recycle it, especially in the case of commercially used plastics. However, if the cross-link bonds are sufficiently different chemically from the polymer bonds, the process can be reversed in some situations. The connection between μ and Tg was found to be significantly linear in the materials studied for epoxy composites. The cross-link density is calculated by using the equation $\mu = dN/(1.5\,M_c)$, where μ is cross-link density, N is Avogadro's number, and M_c is the prepolymer molecular weight.

2.2. Fabrication Process and Testing of Composite Laminates. The use of natural fiber from a plant for the application of renewable sources in developing composite materials has gained attention over the last decades, and natural fiber polymer composites (NFPC) are generally prepared by the encapsulation of a polymer matrix layered with natural fibers. A void is a pore in a composite material that is not filled with polymer and fibers. Voids are usually the product of poor material manufacture and are generally considered undesirable. Due to the entrapped air from resin mixing (such as bubbles in the resin) that is not eliminated before curing, voids are common in composite materials. Depending on the manufacturing procedure, the trapped air may be found in resin films or liquid resins. For thermoset composites, the most popular way is to use a vacuum bagging system in conjunction with a pressure and heat autoclaves. This works because the vacuum system physically removes the voids from the system [20]. The mechanical behavior and material properties of these nanocomposites using two-step micromechanical homogenization procedures in an energy-based approach that incorporates the strain-displacement relationships of a shear deformable beam, plate, and shell theory. The impacts of various nanofillers are discussed in depth, presenting readers with the most effective ways to improve nanocomposite stiffness [21]. These thermoset plastics are generally cross-linked polymers using heat, pressure, or irradiation. Hence, the structural properties of the thermoset polymers possess high flexibility, modulus, and tensile properties [19]. In this work, the composite laminates of 45% of reinforcement, 5% of filler, and 50% of matrix materials were contained and it was fabricated by hand layup technique with five different sequences of weight fractions of banyan/ramie fibers 250 g/50 g, 200 g/100 g, 150 g/150 g, 100 g/200 g, 50 g/250 g, and 30 g granite nanoparticles used in all samples; the stacking sequence of banyan/ramie fibers are shown in Figure 1 and to quantify the effects of dynamic mode of composite laminates.

The fiber materials of ramie mat and banyan mat were selected for reinforcement and to improve the basic strength and withstand more than the atmospheric temperature of the composite by incorporating the filler material of granite nanoparticles and to increase the bonding between the fibers, fillers by adding the matrix material of epoxy resin with a hardener ratio of 10 : 1 can improve the curing time which is used to reduce the porosity due to atmospheric condition [22]. The materials are prepared as per the fiber volume fraction and by using a steel mold 30 cm × 30 cm box to fabricate the composite laminates; initially, the box has been cleaned and liquid wax was applied for avoiding damage to the laminates during the laminate removal stage and applying the predefined epoxy matrix with filler blended thoroughly by using a magnetic stirrer and then applied the matrix as the first layer on the mold box for bonding between the fibers and good surface finishing by composite laminates, then keep the first layer of ramie fiber mat following with epoxy matrix and the second layer of banyan fiber mat was kept and each layer of fiber material contains 50 g, and the sequence is repeating as per formulated layers of composite sample A and the actual and micro images of banyan, ramie fibers and fabrication process as shown in Figure 2.

After the complete fabrication process, the laminates are compressed by 10 kg weight for 24 h and then removed from the mold box, and the sample can be used for dynamic testing [23]. The process has been repeated for all five samples, and the weight fractions of composite laminates are given in Table 3. The fiber volume fraction for these composite laminates is calculated by using the formula as in [23]

$$V_f = \frac{\left(W_f/\rho_f\right)}{\left(\left(W_f/\rho_f\right) + \left(W_m/\rho_m\right)\right)}, \quad V_f + V_m = 1, \tag{1}$$

where V_f is the volume of fiber, V_m is the volume of the matrix, W_f is the weight of fiber, W_m is the weight of matrix, ρ_f is the density of fiber, and ρ_m is the density of matrix.

The banyan and ramie fibers were fabricated to examine the storage modulus, loss modulus, and damping factor as a

Table 1: Physical properties of ramie and banyan fibers [16, 17].

Properties	Ramie fiber	Banyan fiber	Granite particles
Category	Natural fiber	Natural fiber	Ceramic filler
Type	Bidirectional woven fabric mat	Bidirectional woven fabric mat	Nanopowder
GSM	200	200	—
Fiber diameter	0.241 mm (average)	0.196 mm (average)	100 μm (average)
Density	1.50 g/cc	1.69 g/cc	2.65 g/cc

Table 2: Chemical properties of banyan and ramie fibers [17].

Properties	Ramie fiber	Banyan fiber
Cellulose (%)	68.6-76.3	70-76
Lignin (%)	0.6-0.7	3.9-5.9
Moisture (%)	7.5-17.2	6.3-12.7
Hemicellulose (%)	13.1-16	19.2-21.5
Pectin (%)	1.9	0.8
Wax (%)	0.3	0.7

Figure 1: The stacking sequence of hybrid composites.

function of temperature variation, and the experiment was conducted with a single cantilever mode DMA as per ASTM E831-03 standard. The composite samples were prepared as per the standard $25 \times 10 \times 4\,\text{mm}^3$ in each sample of A to E, and this experiment revealed 2% of deflection during the mode of atmospheric temperature from 28°C to 200°C. The viscoelastic behavior of this composite can take from this experiment and examine the storage modulus, complex modulus, loss modulus, and tan delta of the hybrid composite as identified [24]. Tested samples of the hybrid composite are shown in Figure 3.

3. Results and Discussion

3.1. Storage Modulus (E') of an Epoxy Composite. In this work, dynamic mechanical analysis was conducted on the hybrid composite to examine the viscoelastic behavior of laminates. The viscoelastic properties are storage modulus, loss modulus, and tan delta. Figure 4 shows the storage modulus of banyan/ramie fiber laminates. The storage modulus (E') is the most important feature in determining a composite's load-bearing capability since it reflects the elastic component of the viscous elastic material. It also provides information on material toughness, grade of crosslinking, and fiber/matrix interfacial attachment [25].

The solid region indicates that composite laminates are bonded with other materials which are significant properties of all samples; this dynamic mechanical analysis can reveal the developed composite bonding capacity during the increasing of temperature with viscoelastic behavior of hybrid composite [26]. As the ratio of crystalline to amorphous regions increases, cellulose fiber stiffness increases, and flexibility declines. While increasing crystallinity provides more strength, lowering crystallinity means more elongation, more water intake, and more chemical reaction sites available and the degree of long-range order in a material, which has a significant impact on its quality. A polymer's chains are more regularly aligned, the more crystalline it is. Hardness and density rise as the degree of crystallinity increases [27]. However, in this composite, the laminates are amorphous materials, and the above graph revealed, the storage modulus of all samples, the graph between storage modulus and the temperature was used to identify the elastic region of the hybrid composite, and the results have shown that sample A contains more stiffness and has high elastic properties compared with other samples. Sample A consisting of more amount of banyan mat was given significant storage modulus and stiffness over other samples, when increasing this banyan fiber quantity along with ramie fiber and epoxy matrix was given good elastic behavior of composite laminates. Recently, researchers have attempted to decipher the chemical mechanisms that lead to a large increase in elastic modulus when the nanofiller content exceeds the matrix Tg. Mechanical contributions are the primary source of reinforcement in nanofilled glass polymers. At longer durations or higher temperatures, the contribution of molecular stiffening becomes critical and due to substantial chain confinement via interaction with filler surfaces at considerably lower filler content than predicted using uniform particle spacing, random particle packing is critical for boosting chain incremental stiffness [28]. The maximum storage modulus of 1580 MPa was identified during the temperature of 93.8°C and a minimum of 290 MPa at 185°C, and when initiating the experiment at 28°C, the storage modulus of 580 MPa in sample A, which indicates a 12% higher stiffness contained in this sample A at the temperature of 93.8°C compared with sample B which contains 200 g of banyan and 100 g of ramie fibers (2 : 1). Sample E has a 29% lesser storage modulus compared with the sample ratio and different fibers of composites in sample A. Therefore, when increasing the fiber mat of banyan was given significant results in this mode dynamic analysis. The graph also revealed the solid-state, glass transition region and rubbery region of epoxy composite laminates, the starting temperature of 28°C to 80°C having a solid region of all composite laminates, and at a similar period, the glass transition temperature covered at 80°C to

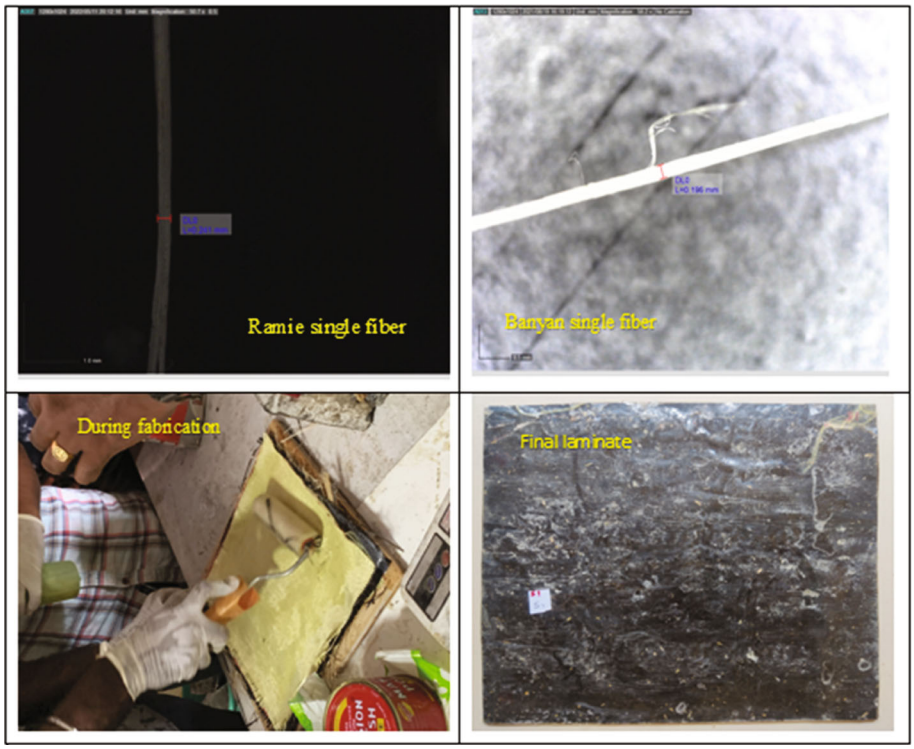

Figure 2: The fabrication process of composite laminates.

Table 3: The weight fraction of ramie/banyan fiber composite laminates.

Sample	Epoxy matrix in g	Granite powder in g	Volume of matrix (%)	Banyan fiber mat in g	Volume of banyan fiber (%)	Ramie fiber mat (%)	Volume of ramie fiber (%)	Laminate weight in g
A	330	30	50	250	37.5	50	12.5	660
B	330	30	50	200	30	100	20	660
C	330	30	50	150	24	150	26	660
D	330	30	50	100	17.5	200	32.5	660
E	330	30	50	50	10.3	250	39.7	660

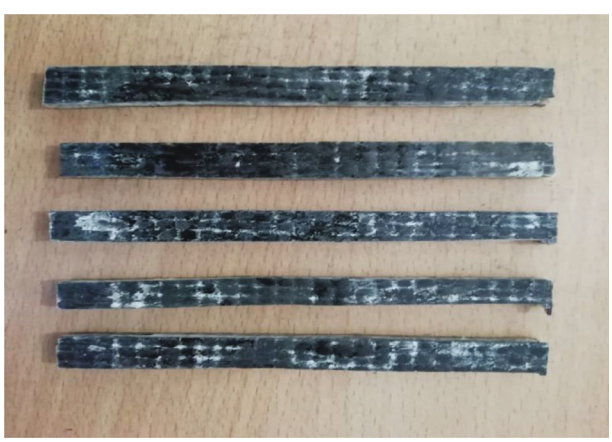

Figure 3: Tested samples of hybrid composite.

110°C of the hybrid composite; after this temperature, the materials move to the rubbery region which was identified from this dynamical analysis. In another work, a composite made of neem and banyan fibers indicates the significant storage modulus of 1150 MPa with more amount of banyan woven fabric, and the chopped neem fiber breaks early when increasing temperature [29]. Pure epoxy has E' of 449 MPa at 25°C and drops to 596 MPa at 120°C when it passes through the glass transition (Tg). The results show that the reinforced fiber significantly reduces modulus drop when traveling through Tg. At 120°C, hybrid composites (bamboo) B : (kenaf) K: 50 : 50 had the greatest E' with 133 MPa, while hybrid composites B : K: 70 : 30 and B : K: 30 : 70 had similar E' with about 76 MPa. In hybrid composites B : K: 50 : 50, the greater E' in the rubbery zone indicates a stronger fiber/matrix interfacial connection allowing stress transmission from the matrix to the fibers [30]. Therefore, the ramie fibers and granite particulates play an important role in this composite laminate, because the banyan fibers are blended with ramie fibers and granite particulate was identified with a maximum storage modulus of 1580 MPa compared with the above work with 27% more stiffness of this hybrid composite. The sample containing an equal amount of banyan and ramie fibers was identified with a 21%

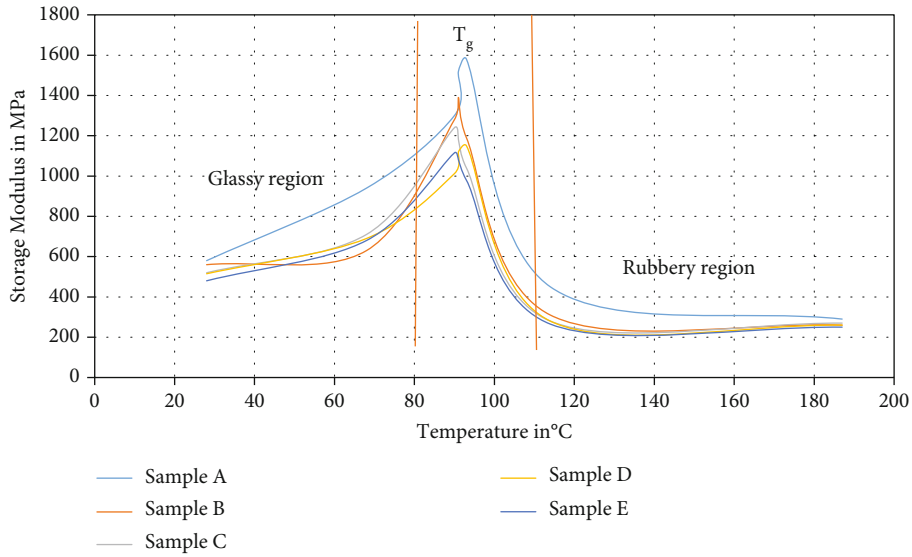

Figure 4: The storage modulus of the epoxy composite.

lower storage modulus compared to the sample A, which indicates when the increasing of banyan fiber weight, the fraction of ramie fiber shows the positive influence of composite laminates. The storage modulus of all samples was decreased with increasing temperature due to the loss of stiffness at more temperatures in the hybrid composite. The free volume of the component grows as the temperature approaches the glass transition area and the molecular mobility increases. The modulus of the glass transition zone drops dramatically; as a result, there were no apparent changes in E' in the rubbery region.

3.2. Loss Modulus (E'') of an Epoxy Composite. The loss modulus revealed the viscous behavior of the hybrid composite and the amount of heat dissipation during the temperature increase by the dynamical analysis. The loss modulus of the developed natural fiber-reinforced hybrid composite will be determined using dynamic mechanical analysis. The heat debauchery of the composite throughout the pressure cycle is defined by the loss modulus, which also specifies the viscous possession of the hybrid composite [29]. The loss modulus of epoxy hybrid composite laminates is shown in Figure 5. In this experiment, five different sequences were selected to quantify the loss modulus by conducting this DMA, and the results show the viscous response and heat dissipation with peak values during the temperature increasing from 28°C to 200°C; the samples are having moderate loss modulus up to 80°C, and once it reached glass transition temperature (Tg), all samples are having high viscous and peak height also more during the temperature between 80°C and 105°C. However, sample A shows a high loss modulus of 298 MPa at 93.8°C; this sample A during the initial stage 140 MPa of loss modulus was identified, and when increasing the temperature, the solid material of composite laminates moves to the glass transition temperature and dissipates high heat to their temperature limit of 105°C and then it moves to the rubbery region and the loss modulus also get reduced to lower value of 40 MPa. Similar work has been carried out using the epoxy matrix without any reinforcement to analyze the dynamic property of epoxy matrix loss modulus given 258 MPa at the glass transition temperature of 79°C. This result shows that the epoxy matrix has a high range of energy dissipation when compared to the composite fabricated with fiber reinforcement [30]. In sample B containing 200 g banyan fiber and 100 g ramie fiber remained the supreme loss modulus of 280 MPa, and this result is 17% lower than sample A; it can indicate that an increase of 7.5% ramie fiber weight fraction in total composite laminates was given the negative influence of loss modulus compared with sample A.

Therefore, the banyan fiber properties have significant viscous compared with ramie fiber during the polymer matrix composite and the other samples C, D, and E also were given a similar response when the increase of banyan fiber weight fraction was identified to improve in loss modulus and dissipating high heat compared with ramie fiber loading of composite. This can be used to determine whether the adding of the usual fibers consumed resulted in an upsurge in free volume and the continuation of the procedure in the polymeric matrix's construction [28]. In the sample, C shows a 20% lower loss modulus during the operating temperature and it can be reduced when increasing the temperature; maximum loss modulus achieved in sample C is 272 at 90.2°C. The difference between the initial stage in peak height is 12% reduced and 10% during the rubbery region in sample C. This sample C was identified with 8% less loss modulus at 90.2°C when compared with sample A during the same peak height temperature of composite laminates. This is evidence that adding natural fibers increases internal friction, which increases the dissipation energy, as documented by other researchers [29]. Among the five samples, sample E was given the lower loss modulus of 215 MPa during the maximum peak height at 91.1°C and it was 27% less than sample A; therefore, when the enhanced fiber loading of banyan was given a positive influence on the viscous behavior and heat dissipation energy at glass transition temperature compared with ramie fiber loading of this polymer composite laminates. The molecular

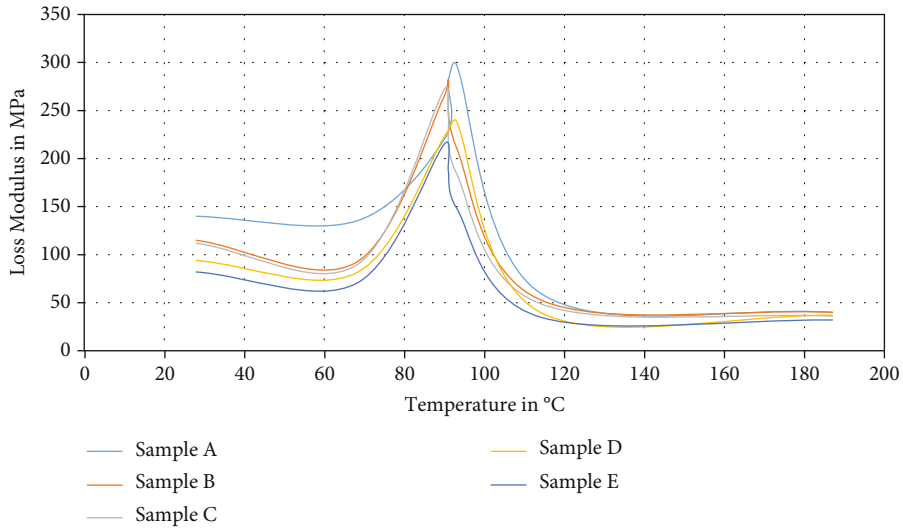

Figure 5: The loss modulus of an epoxy composite.

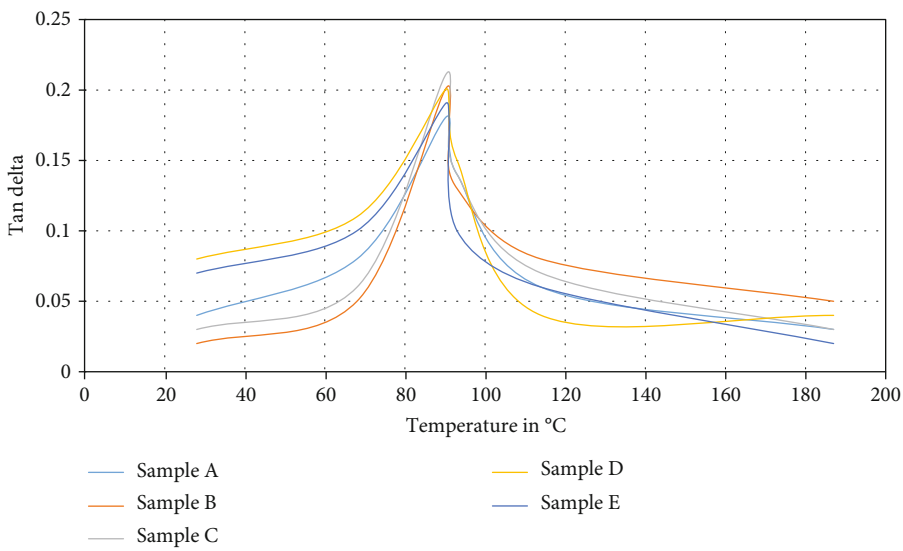

Figure 6: The damping factor of an epoxy composite.

segmental motion is activated as the temperature approaches the glass transition area. When the sample's timescale molecular motion collides with the mechanical deformation, the result is the highest conceivable internal friction and nonelastic deformation [30].

*3.3. Damping Factor of Epoxy Composite (*tan δ*).* The graph between tan delta with temperature is shown in Figure 6. The damping factor denoted as tan δ is used to identify the damping capacity of composite laminates, tan delta is the ratio between the storage modulus to loss modulus, and it can reveal the material behavior during their rubbery region. tan delta represents the ratio of elastic (E') to viscous (E'') properties. A high number imply that there is a lot of energy dissipation and, as a result, a lot of nonelastic deformation; on the other hand, a low value shows that the material is more elastic. The tan delta rose with increasing temperature, reaching a maximum in the transition zone before progressively decreasing in the rubbery region. This is because the molecules in the composites are packed tightly and frozen below Tg. The free volume and molecular mobility both rise in the transition area. The molecules in the rubbery zone can move easily with little resistance to the flow; hence, the damping in this region is low [29]. The higher or broader the glass transition behavior, the greater the limitations on the amorphous phase. The highest peak breadth is observed in composites with larger fiber loading, the graph shows increasing the temperature to the response of material damping properties in sample A having more solid material compared with other samples, and the energy dissipation also has a significant peak height and

Table 4: Data of dynamic mechanical analysis.

Properties	Sample A	Sample B	Sample C	Sample D	Sample E
Storage modulus (E') in MPa	1580	1390	1240	1150	1115
Loss modulus (E'') in MPa	298	282	272	239	215
Damping factor (tan δ)	0.18	0.20	0.21	0.20	0.19
Tg (°C)	93.8	91.6	90.2	93.1	91.1

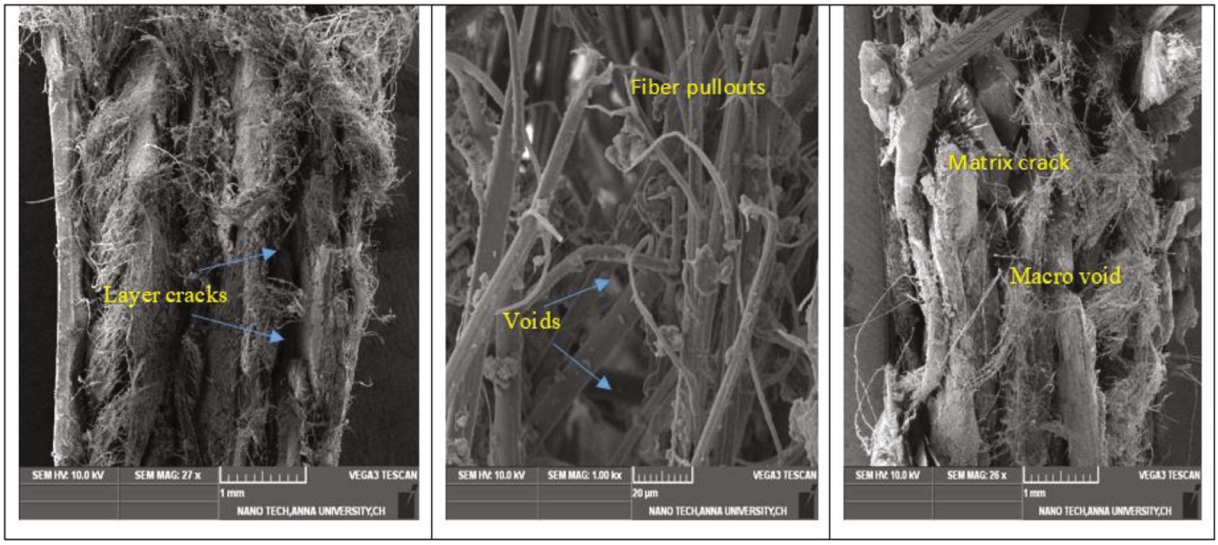

Figure 7: SEM image of hybrid composite.

sample E is showing the more rubbery region and it can indicate the ramie fiber loading is having high elastic property compared with banyan fiber loading.

The tan delta value of sample A during the initial temperature of 28°C is 0.24, and it can be decreased when increasing temperature during the solid-state condition, when the material is having the damping factor of 0.14 and it moves to the glass transition temperature of 80°C to 105°C the value of tan delta range is 0.18 to 0.21. Therefore, it indicates that the banyan fiber loading revealed more solidness of composite laminates when blended with ramie fiber and epoxy composite. In this experiment, the granite filler material was used and it can deliver more solid factors during increasing temperature in all five different samples; however, the fiber reinforcement was given the major impact of this hybrid composite during the dynamical analysis. In the sample, B was given the tan delta value of 0.20 at operating temperature and the same damping factor is continued with the maximum peak height temperature of 91.6°C, and then, it moves to the rubbery region; it reveals the material is more solid and takes more time to attain the elastic stage of the hybrid composite. In sample, C contains an equal amount of fibers placed and it can show similar results like sample B of the tan delta is 0.20 and the lower tan delta value is identified in sample E during their peak height of temperature at 91.1°C is 0.19 and this sample contains 50 g banyan fiber and 250 g ramie fiber loading of composite laminates. Therefore, when increasing the banyan fiber loading was given more solid behavior of the composite and at the same time when the increasing of ramie fiber loading can give more elastic region was identified from this tan delta graph also the granite powder can improve the stiffness of the epoxy composite. Dynamical properties of a pure epoxy matrix at Tg (°C) 79°C: E'—2358 MPa, E''—258 MPa, and tan δ—0.109 [27]. Data of dynamical analysis are given in Table 4.

3.4. SEM Morphology of the Hybrid Composite. The presence of lignocellulosic nature in PCF was confirmed by XRD and FTIR findings. After the addition of PCF, the mechanical test results showed a significant improvement in the characteristics [28]. SEM analysis revealed a drop in filler content, increased load conditions, and increased reinforcement, all of which resulted in larger surface deformations in the composites. The fiber and matrix contents are the most important factors that influence composite characteristics. They have the greatest influence on the composite material's mechanical properties. Although the rule of mixture is not completely accurate, it can be used to estimate the composite material's elastic properties. As a result, fiber and matrix contents are two critical features to assess [29]. The use of a higher weight percentage of banyan fiber in the development of hybrid composites resulted in fewer matrix cracks due to a more uniform stress distribution. Because of the higher level of stress concentration in the material, increasing the weight fraction of ramie fiber in hybrid composites resulted in a more complex level of cracks. SEM image of the hybrid composite is shown in Figure 7.

4. Conclusion

This research work evaluated the dynamic mechanical analysis of banyan fiber and ramie fiber reinforced with epoxy composite and identified the properties of storage modulus, loss modulus, and damping factor of hybrid polymer composite; this experiment was conducted for five different samples and the results were analyzed. The following are major findings of this composite laminates from this dynamical analysis.

(i) The natural fibers of banyan and ramie have significant bonding capacity with epoxy polymer matrix and the granite nanoparticles can improve the stiffness of all hybrid composite samples

(ii) In sample A, the results were improved in the storage modulus of 1580 MPa, due to the addition of more banyan fibers, which can improve the stiffness of the hybrid composite compared to ramie fiber loading

(iii) Similarly, loss modulus shows the viscous behavior of all five samples and sample A contains the high loss modulus of 298 MPa, and this result is an average of 15% higher peak height compared to other samples

(iv) The ramie fiber mat loading is high in sample E showing the damping factor of 0.19, and the rubbery region shows the composite laminates are more inelastic than other hybrid composite samples

(v) Therefore, the results of storage modulus, loss modulus, and damping factor of the tan delta are solidness and glass transition temperature more when increasing of banyan fiber mat layer and at the same time more ramie fiber loading was given the significant elastic property in the rubbery region of hybrid composite laminates

(vi) The dynamical behaviors of banyan/ramie fiber composite were used to develop a natural fiber composite helmet, and it can also be used to develop automobile car interiors due to their retaining capacity during higher temperatures

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Examine the Mechanical Properties of Aluminium Tetrahydride/ Calotropis gigantea Based Hybrid Polyester Composites in Cryogenic Atmosphere

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From the previous scarce periods, the investigation has evolved from traditional resources and compounds and toward frivolous constituents to produce small and hugely influential substances for specific purposes. The foremost goal of the current examination is to explore the effectiveness of aluminium tetrahydride (ATH) filler addition on the Calotropis gigantea fibre (CGF)/polyester-based hybrid composite. The hybrid materials with a 3 mm width and three layers of CGF were manufactured using the conventional technique. To achieve the objectives mentioned above, the following constraints like (i) Wt.% of ATH, (ii) number of CGF Layers, and (iii) cryogenic treatment hours, each at three different levels, were chosen. The composite was fabricated as per the design of L_9 orthogonal array. This research measured the mechanical characteristics like flexural, tensile, and impact characteristics. The materials with 5 wt proportions of filler, 3 layers of CGF and 30 min of liquid nitrogen treatment (A2, B3 and C2) showed better mechanical strength. They were studying the broken specimen's morphological behavior by scanning electron microscopy (SEM).

1. Introduction

Natural-fibre composites are expected to find an expanding number of uses in the coming years, particularly in Europe, where law and public pressures are on the rise. In the discipline of structural engineering, material selection is critical in the design and manufacture of green products. The materials investigate their physical and mechanical characteristics to recover the invention and enhance client fulfillment. Polymeric substances are such resources that give straightforward processing, high productivity, and low cost [1–3]. Compared to manmade fibres such as nylon, glass, and carbon, the natural fibres provide considerable economic efficiencies and manufacturing improvements. Natural fibre

composites, on the other hand, have significantly poorer mechanical characteristics than manmade composite materials. Natural fibre composites also have weak resistance to water uptake, making these lesser appealing [4, 5]. Calotropis gigantea (CG) is a weed native to Asia, with populations in India, Pakistan, Malaysia, Indonesia, Thailand, and China. It is a moderate small evergreen tree that grows up to 4 meters in length and has a waxy appearance and copious milky liquid. Linn (Compositae), also called "Arka" in Sanskrit and "Mudar" in English, is a variety of Calotropis that grow to be quite large. It is considered to be useful against a broad range of ailments in literary works. It is used in naturopathic remedies and as an insect repellent and also has a wide range of medicinal properties [6].

Calotropis gigantea is hazardous as well, producing diarrhea, coughing, pupil dilation, and in some cases, death. It also can be used as a fibre in polymeric composites as a common weed plant [5]. For technical reasons, chemical components of cellulose fibres like lignin extract, alpha-cellulose, ash, and hemicellulose are being researched. The qualities of the CG plant fibre make it suitable for making natural fibre-reinforced laminates. The existence of cellulose has a significant impact on the thermal-mechanical properties of natural fibre-reinforced laminates. The amount of alpha cellulose in the shrub's chemical composition ranges between 58 and 67 percent [7]. Even though natural fibre-based composites are not without flaws, they remain a viable option. Since natural fibres have a lower water barrier, they absorb a lot of water and have poor mechanical properties. Hybrid composites comprise two or more fillers encapsulated in a similar medium. Interbreeding enhances the mechanical qualities of organic textile-reinforced plastic nanocomposite besides removing the drawbacks of a thing [8].

Moreover, the impact of blending fibrils into the matrix has also exceeded its limits in improving physical behaviour. Nanomaterials are being used to strengthen this vow between the fibre and matrix, further enhancing the characteristics. Consequently, the use of nanomaterials in synthetic materials is growing more common. This research focuses on determining how and where to start manufacturing aluminium trihydrate total styrene polymeric wasting flour. Because its global outcome is expected to be approximately 86,300 metric tonnes annually, the ATH could be used as fresh material for innovative products. Liquid nitrogen properties can improve the properties of fiber-reinforced blends. For example, materials being used in aerospace components must be capable of withstanding extreme temperatures reaching up to -196°C. Cryogenically treated nanocomposite materials, as well as polymers, have maximum hardness, more outstanding toughness, and enhanced solidity, as well as fatigue resistance [9]. Consequently, cryogenic treatment of nanocomposites may become an essential part of current research and development to improve natural fibre elastic moduli.

The principal objective of this study is to develop and test combinations of organic nanomaterials for mechanical and physical properties. The ATH, CG fibre content, and merged nanocomposites have been handcrafted. The mechanical performance of a constructed nanocomposite has been evaluated after submerging it in fluid N_2 at 77 K at different times.

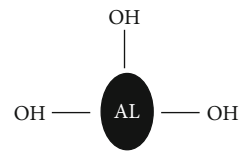

Figure 1: Chemical construction of ATH powder.

2. Investigational Works

2.1. Resources. The GVR fibre industry in Madurai, Tamil Nadu, India, provided the knitted CG fibre mates. The CG fibre pals have been cautiously laved with potable water and dried in the sun for two days to remove any moisture. After the CG fabric has been immersed in NaOH solution for 4 hours, it is carefully laved in clean water and placed in mesh at 75°C. This research used HN361 alumina trihydride (ATH) and an epoxy matrix. Naga Chemical Compounds Companies provided the Matrix and ATH fillers in Mumbai, Tamil Nadu, India. The chemical structure of ATH is exhibited in Figure 1. The retrieval of CGF pal from CG Stems is depicted in Figure 2.

2.2. Creation of Hybrid Composites. Initially, a steel moulded by a size of $150 \times 150 \times 3$ mm was refined. The polymer solution was mixed thoroughly with 1% cobalt naphthenate and 1% methyl ethyl ketone peroxide. The hand lay-up method was employed to build the matrix out of ATH granules and knitted CG natural fibre. By manually stoking with such a glass slide, different weight percent of ATH granules were distributed inside the generated polyester. The above concoction has been strewn over the fibre strands of the molding. After composite combos have wetted fiber inserts, the preform has been held in place and thirsty in the outdoors for one day moistened by matrix combinations. L_9 Desiccators were employed to prevent the combination mixtures from assimilating any more humidity. Following that, the manufactured specimens were submerged in fluid N_2 at 77 K orthogonal range was used according to Taguchi configuration for three conditions, each with three phases, and nine polymeric panels were designed for more research. The parameters are listed in Tables 1 and 2, along with their ranges and Taguchi's orthogonal arrangement (OA). Using the Taguchi method, this variety was employed to effectively structure the process conditions. This method has been heavily used to create the reaction conditions.

2.3. Testing of Composite Specimen. The elastic modulus sections were produced to ASTM D-638-03 recreations with dimensions of $150 \times 15 \times 3$ mm for tensile loading, ASTM D-790 (depth 10 mm, length 125 mm, and depth 3 mm) for bending tests, as well as ASTM D-256 for impact.

2.4. Scanning Electron Microscope (SEM). Microscopic examinations of fragmented polymeric specimens were carried out using SEM. Prior to SEM clarification, the samples were laved, thirsty, and ground to a thickness of 10 nm to increase the conductivities of the blends.

Figure 2: Extraction of CGF mate from CG plant.

Table 1: Constrains and their stages for composite.

Sl. no	Constrains	Symbols	Stages S1	S2	S3
1	ATH powder (wt.%)	A	2.5	5	7.5
2	No of CG fibre layers (no)	B	1	2	3
3	Cryogenic handling (min)	C	15	30	45

Table 2: L_9 orthogonal array.

Trail no.	ATH powder (wt.%) A	No. of CG fibre layers (no) B	Cryogenic handling (min) C
1	2.5	1	15
2	2.5	2	30
3	2.5	3	45
4	5	1	30
5	5	2	45
6	5	3	15
7	7.5	1	45
8	7.5	2	15
9	7.5	3	30

3. Result and Discussion

The mentioned discussion briefly explains the mechanical behaviours of polymer composites such as tension, flexural strength, and impact predicated on one 's input variables.

3.1. Effect of ATH Filler Additions. Figure 3 depicts the success of ATH fluff expansions in terms of ductile, bending, and impact strength. 5 percent ATH inclusions outperformed 2.5 and 7.5 percent ATH inclusions in structural properties. The enhanced pressure distribution as well as transmission may be responsible for the heightened mechanical properties of ATH in epoxy at a concentration of five weight percent. Extra packed ATH added to a polymer matrix enhanced the method of transport and dimensions of gaps, trying to influence the decohesion togetherness between filler particles [6]. As a result, at an accumulation of 5%, the material, knitted CGF, and ATH preparations provide adequate adherence conditional between exterior scar tissue. The addition of 2.5 and 7.5 Wt. percent ATH, on the other hand, produced a negative result, implying a reduction in structural rigidity. Moreover, thicker and softer axial loads of 2.5 and 7.5 weight percent were seen in poor bounding compliance of reinforcement and resin in knitted CGF as well as polyamide, culminating in agglomeration due to poor bonding as well as inadequate reinforced intensity characteristic [10].

3.2. Effect of Number of CGF Woven Layers. The efficiency of ductile, flexural, and impact features of knitted CGF strands is depicted in Figure 4. Once compared with single as well as double-surface CGF, three levels of CGF showed impressive tensile stability. This is because CGF fabric is the massive primary element in ATH as well as CGF-based combination fabric nanocomposite. The fabric with NaOH treatment improves the fibre surface contact. As a consequence, so much energy must be expended to rupture the bonds between the interrelated packages of fibres within the blends [11, 12]. The fabric made famous by solitary CGF fibres could withstand a light load. As the weight percentage of CG fibres in the composite materials rises, so does the ability to support so much weight. The stress causes failure and also has more excellent deformability as the percentage of CG fibre within the layered combination reinforced increases [13].

3.3. Effect of Cryogenic Treatment. In cryogenic handling, the composite material slab has been immersed in fluid N_2 at -196°C and thermally cycled. The plasma treatment of thermoplastic composite materials is an innovative approach to enhancing material characteristics. The effect of supercooled ability to handle on the material properties of thermoplastic nanocomposites is depicted in Figure 5. It also demonstrates that 30 minutes of intervention resulted in severe tensile of 30.73 MPa, bending characteristics of 35.42 MPa, and impact resistance of 23.15 kg/m^2. It could be due to residue left stresses induced by concrete strength interaction as a consequence of appropriate product supercooled effort. At cold temperatures, internal forces are formed due to matrix changes and fibre contraction. The interaction pressures referenced above aid in keeping the fabric as multiverse in interaction and improve bonding, resulting in more efficient effects [8, 11, 12].

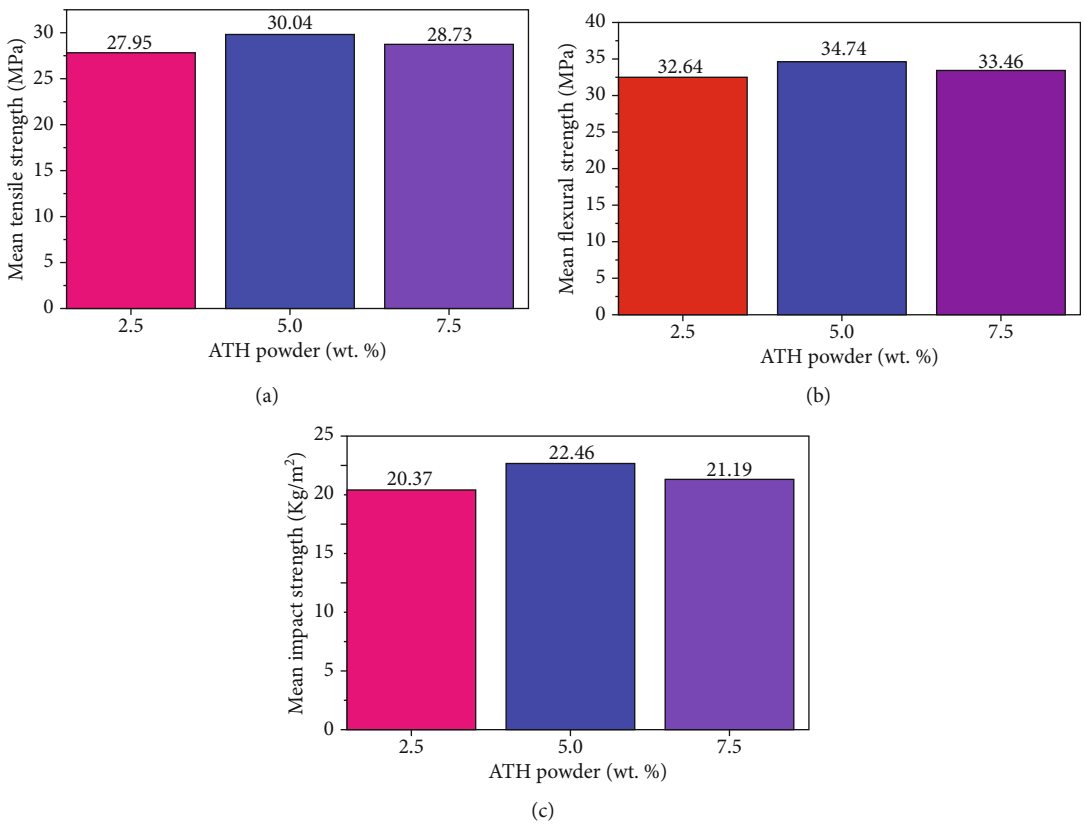

Figure 3: Result of ATH filler addition on the mechanical characteristics.

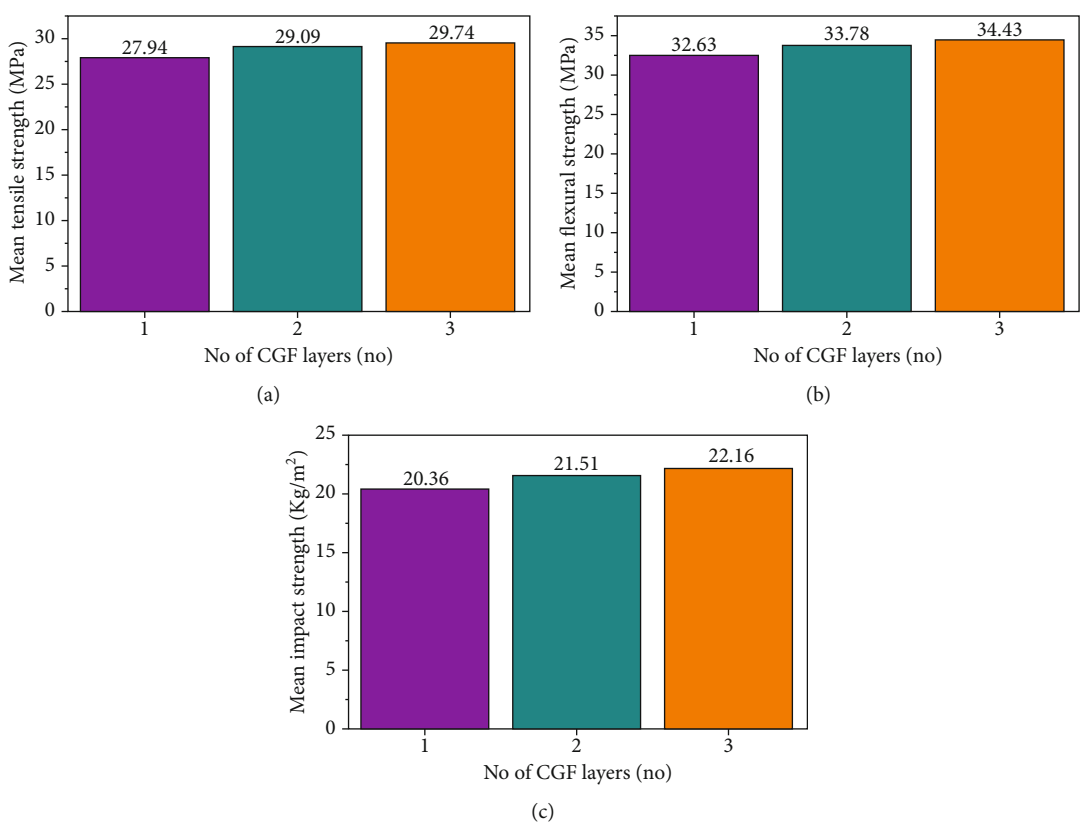

Figure 4: Result of woven CGF layer addition on the mechanical characteristics.

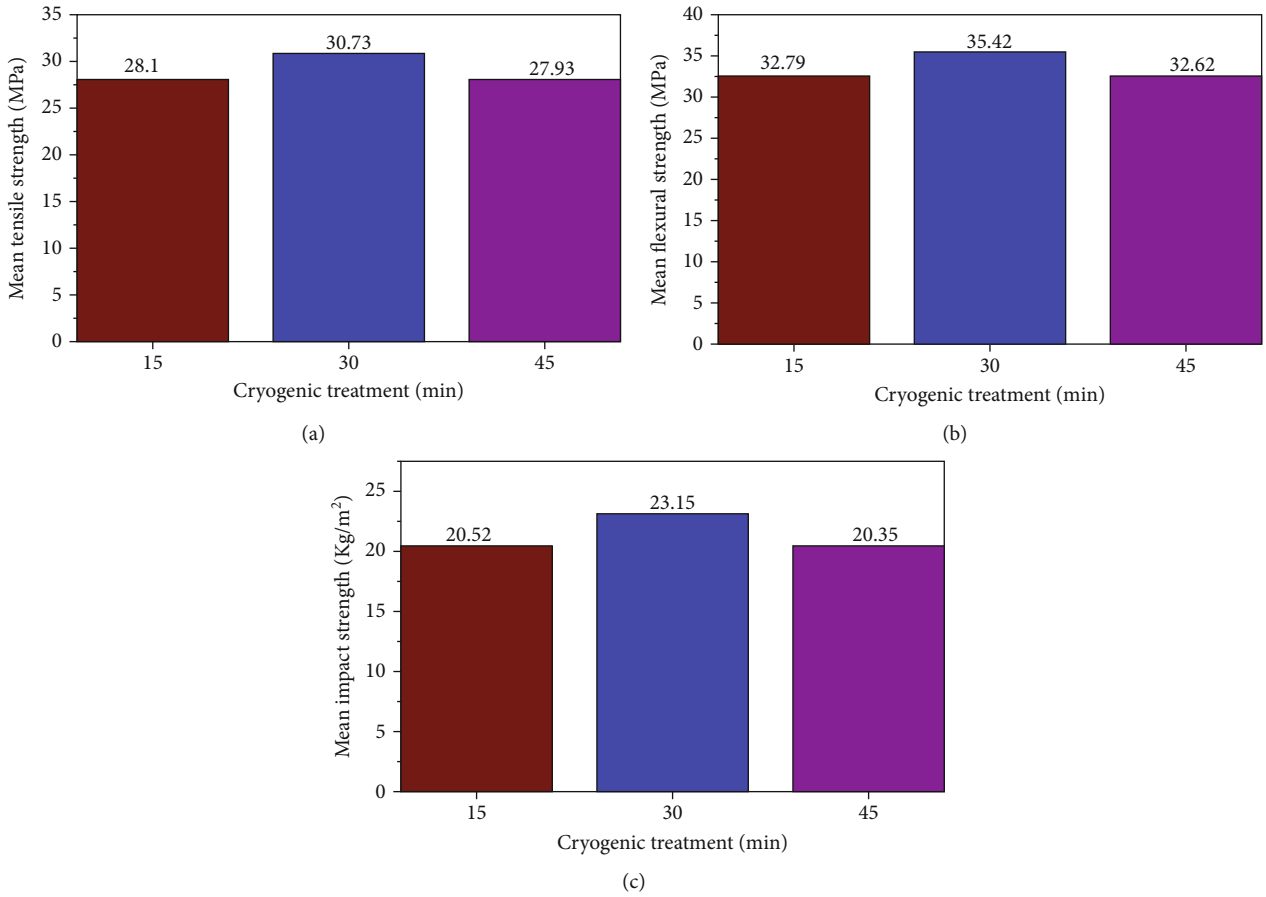

Figure 5: Result of cryogenic treatment on the mechanical characteristics.

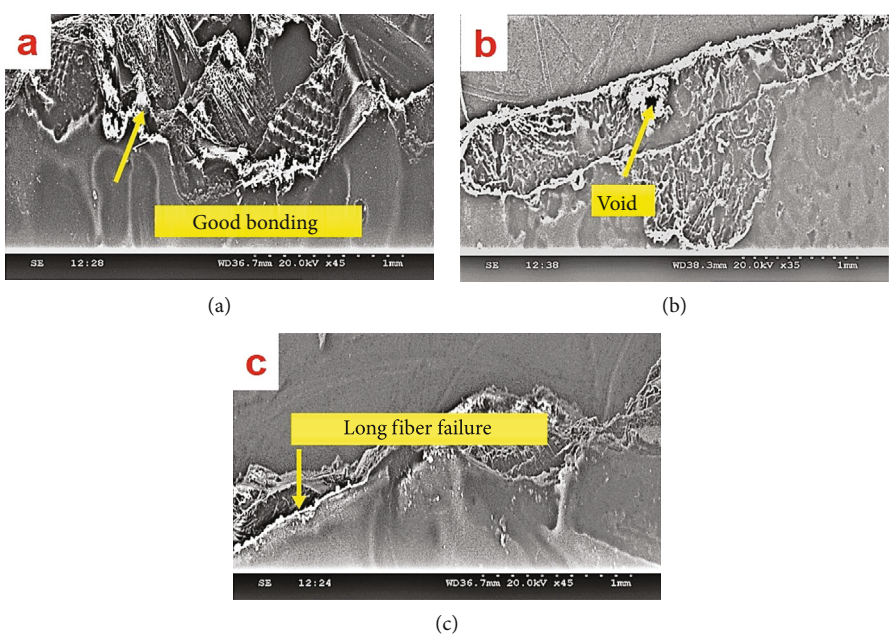

Figure 6: SEM image of cryogenic handling of the composite specimen.

4. Microstructural Analysis

The shattered surface of a hybrid composite specimen after 15, 30, and 45 minutes of cryogenic treatment is shown in Figure 6. It could be due to residue left stresses induced by flexure interaction as a consequence of appropriate product supercooled effort. At a relatively low temperature, internal forces have been formed due to composite changes as well as fibre contraction. This type of interaction strain aids in keeping the fabric and composite in interaction as well as improves adherence, which leads to better results. The supercooled stress corrosion cracking of composites makes them firmer at colder concentrations. Even as the rigidity of the specimen reduces, so does its flexibility, culminating in less diversion [14, 15]. The mechanical characteristics of hybrid samples declined when samples are treated for longer than 30 min. Extended cryoprocessing durations may result in greater thermal stress because of the increasing quantity of fabric misfit. Caused by lower interaction, delamination is a much more damaging composite structure. It could be because it significantly reduces the time required to heal the laminates. Huge debonding areas in reduced epoxy blends amplify a few prospective rupture hazards. The reduction in temperature increases among specimens leads to a rise in tensile stress in the nanomaterials handled after 30 minutes. The aforementioned findings lead to the breakdown of a tested laminate [8].

5. Conclusion

The mechanical characteristics of ATH-filled woven CGF/polyester-based hybrid composites were manufactured and examined in this experimental study. The following are the findings reached.

Controllable process variables for ATH and CGF based hybrid composites should be set at 5% ATH, 3 layers of CGF, and 30 min of cryogenic handling. A variety of variables combine to produce a nanocomposite with improved mechanical properties.

The stress concentration produced solely during interaction has been stiffer, promoting comprehension and practise throughout the first 30 minutes of intervention.

When the number of CGF layers in the hybrid composites was increased, the results were positive. The interaction zone between the fibre and the matrix has enhanced as the fibre content has augmented. As a result, additional energy is required to breakdown interweaved fibre packages' connection.

The residual stresses that generated at the interface during the cryogenic treatment were compressive, assisting in greater matrix-fibre adhesion, but only for the first 30 minutes of treatment.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Effect on Compression Molding Parameters in Mechanical Properties of MWCNT/Glass Fiber/Epoxy Composites

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Reinforcing fibers, nanofillers, matrix materials, and manufacturing techniques all have a role in the mechanical characteristics of hybrid composites. MWCNTs-reinforced E-glass/Kevlar/epoxy composites are appropriate fillers for structural applications. The impact of different concentrations of MWCNT fillers (0.4%, 0.8%, and 1.2% wt) on the mechanical characteristics of hybrid composites has been studied. Tensile and bending strength, as well as hardness, were measured in compression-molded composites. The effects of compression pressure, mold temperature, and applied pressure on hybrid (0.8% MWCNT) were investigated. When it came to composite tensile and bending strength, compression pressure was the most important factor, closely succeeded by mold temperature and pressure period. Compression molding were optimized, resulting in a tensile strength of 183 MPa, a bending strength of 158.3 MPa, and a hardness value of 23.8 HV.

1. Introduction

Composites are taking the place of traditional materials due to their low cost and high productivity in manufacturing and processing [1]. Polymeric materials are superior to nonpolymeric materials in a wide range of applications, including structural, automotive, electrical, marine, biomedical, and chemical parts [2, 3]. For the above-mentioned uses, polymer composites made with synthetic or else natural fibers were widely used. Composite structures can benefit from the superior stiffness and strength of synthetic fibers (such as basalt, Kevlar, glass, and carbon) when used for load-bearing purposes [4–6]. Glass-fiber reinforcement has outstanding mechanical and thermal qualities that are ideal for aeronautical use. To make ballistic armor, bulletproof, and other various protective materials, polymer composites are made using matrix material [7, 8]. Using epoxy resin as the matrix material for hybrid composite parts has been

shown to increase their tensile, flexural, and impact strength significantly. Epoxy matrix also reduces composite part density by 3.12 percent, allowing for the production of lighter components [9–11]. Sui for aerospace applications, GFEC assessed for adhesive bonding strength exhibits high adhesion. Polymer composites with improved strength and hardness can be made by combining synthetic fibers through epoxy materials and its manufacturing methods [12]. There is an information in Table 1 about the materials and characteristics of polymer matrix composites (PMCs). With significant qualities (physical and mechanical as well as tribological) in epoxy composites, they were best suited for use in many different applications. Polymer matrix composites (PMCs) are made up of fibers that enhance the composite's structural integrity and provide protection from corrosion and heat resistance [13–16].

Figure 1 shows different materials for composite preparations. Epoxy resins have great strength making more useful in aircraft, automobile, and marine applications, despite the large variety of matrix/binding elements utilized [17]. Hydraulic cylinder weight was reduced by 96%, excavator engine hood wear resistance was improved, and engine frame weight was reduced, while stiffness and strength were improved. These techniques include spray-up, resin transfer molding (RTM), and other methods such as vacuum infusion or vacuum-based RTM, compression molding, pultrusion, and filament winding [18, 19]. Compression or hot-pressing procedures require less tool than other processes, but each has advantages and disadvantages. It is possible to produce compound shapes with outstanding dimensional solidity, repeatability, mechanical properties, and spark resistance using the compression molding technique. Compression molding processes for epoxy-based FRPC need to be studied further, according to the aforementioned literature study [20–22].

To make high-strength composite compounds for the automobile and aircraft industries, compression molding is the preferred method. Compression molding was used to create carbon-fiber epoxy composites with improved mechanical properties [23, 24]. Nonwoven mats made of natural fibers and polylactic acid were molded at high temperatures using a compression molding progress. After improving the molding conditions, woven flax/PLA polymer composites made via compression molding had higher impact strength (temperature, pressure, and time). Sheet-molded CFR composites have even more strength and stiffness when exposed to compression molding techniques. Polypropylene materials were examined by [25] for the influence of compression molding temperatures on their viscosity. Viscosity and melt flow velocity of PP are reversed when molding temperature is incorrect. Compression molding factors like as mold temperature, pressure, and duration are critical to the success or failure of thermoset items made using this process [26]. In composite parts, compression molding is an excellent approach for improving qualities that may be found in the preceding literature when the molding parameters are properly adjusted.

Reinforcing epoxy composites with micro- or nanofillers and nanofibers has been a major focus of current research publications, which have improved structural, mechanical, thermal, tribological, and functional qualities [27]. For better performance in engineering materials, fine particles and fillers have a higher aspect ratio and surface area per unit volume than microparticles. A strong interfacial bond between the nanofillers and the fibers is critical to transmitting load from the matrix to the fiber. Epoxy composite filler materials including carbon nanostructures can also improve thermal characteristics. The incorporation of MWCNT to nickel-cobalt materials increases supercapacitor characteristics of electrochemical [28]. MWCNTs are reusable. An increase in compressive strength and reduced shrinkage was achieved by using MWCNTs as nanoreinforcements in hybrid epoxy composites (MWCNT/silica fume cement). The compressive properties of hybrid polymer composites are also improved when MWCNTs are included [29]. Furthermore, it is necessary to do further research into the mechanical and tribological properties of carbon nanotube-based hybrid composite materials.

Despite the fact that the available literature contains a plethora of studies examining the mechanical performance of fiber-reinforced epoxy composites [30, 31], hybrid nanocomposites research, on the other hand, is still mostly under-reported to this day. Thus, our aim is to study the influence of factors on mechanical properties of compression-molded polymer composites completely in this work.

2. Materials and Methods

2.1. Materials. Fiber-reinforced plastic has a high level of strength due to the transmission of loads from the matrix to the fibers. Interlaminar bonding between matrix and fiber shear strength are all factors in this phenomena. With over 10 million tons of global yearly output and over 95% of all fiber reinforcement coming from glass fiber, the composite sector relies heavily on this lightweight material with an excellent performance to cost ratio. The primary reinforcing materials in this investigation were 250 gsm (g/m^2) woven E-glass fabrics with a diameter of 12 mm. The following elements are found in E-glass fiber: There are 52-56 percent SiO_2, 12-16 percent Al_2O_3, 16-25 percent CaO, and 8-13 percent B_2O_3 in that mix, for a total of 52-56%. One of the principal reinforcing fibers in composite laminates is Kevlar fiber, which also goes by the name PPTA aramid fiber because of its strong rigid molecular structure. 90% pure MWCNTs (multiwall carbon nanotubes) were employed as a nanofiller in hybrid composites. They have a vast scope of current and emerging uses, including superior structural composites, conductive polymers, battery cathodes, solar arrays, battery packs, nanoelectronics, semiconductors, and power storage. MWCNTs were manufactured by chemical vapor deposition and have the following dimensions: outer diameter of 10-15 nm, interior diameter of 2-6 nm, and length of 1-10 mm.

2.2. Experimental Details and Methodology. Surface contaminants on the MWCNTs were first removed by rinsing them in deionized water. It took three hours to ultrasonically dissolve nanotubes in epoxy resin, which have an average

Table 1: Physical and mechanical characteristics of filler and fibers materials [27].

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Elongation on break (%)	Tensile modulus (GPa)
Kevlar	1.51	3100	2.6-3.8	65
E-glass	2.6	2100-3600	0.6	75
Multiwall carbon nanotube	2.0	100,000		1300

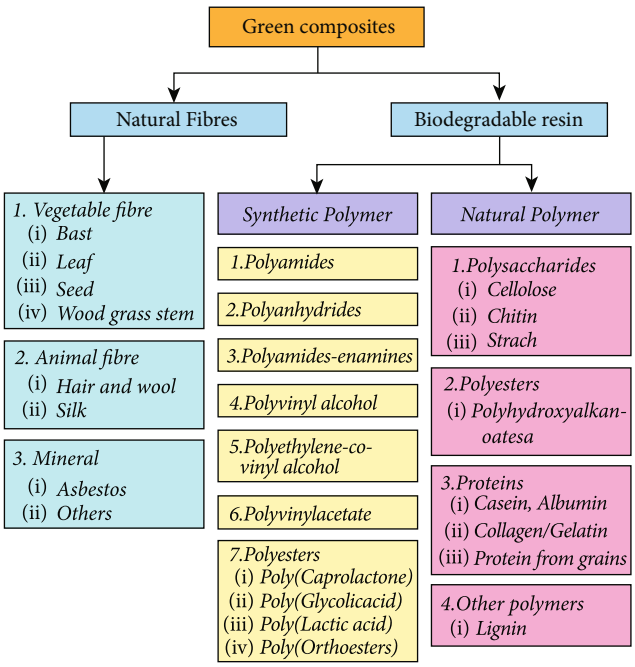

Figure 1: Different materials for composites.

Table 2: Epoxy matrix properties [31].

Property	Corresponding value
Density (g/cm^3)	1.28
Youngs modulus (Mpa)	3300
Tensile strength (Mpa)	87.2
Poisson ratio	0.38

diameter of 10 to 15 nm and an average length of 1-10 mm. A magnetic stirrer was used to mix the epoxy and MCWNTs with K-6 Hardener, ensuring that the nanoparticles were dispersed. All three MWCNT weight-percentage hybrid composites are created with the following: glass, Kevlar, and epoxy. Table 1 shows the physical and mechanical characteristics of filler and fibers materials. Table 2 shows epoxy matrix properties. Agglomerations which impair mechanical characteristics occur when carbon nanotubes make up more than one weight percent of a composite matrix. However, the properties of MWCNTs with varying weight proportions were found to vary after showing lab tests and consulting literature. It is therefore being attempted to establish the ideal percentage of MWCNT in hybrid composites to achieve bending, tensile, and hardness.

Layers of composites are assembled. It was covered with a nanofiller-reinforced matrix on every layer of bi-directional fabric. For automotive and industrial applications, compression molding can produce high-strength sheet molding parts. Figure 2 shows a schematic representation of the compression molding process experimental set-up. As a result of the introduction of heat to the vice, compression molding is sometimes known as a "hot press." Compression molding's experimental set-up appears to be small, with the supporting structure resting on a firm base. Hydraulics can move up and down the press thanks to the press's four slide pillars. Electricity is used to heat the bottom or lower platen to a predetermined temperature of 120°C. Figure 3 depicts the key phases in compression molding method for producing composite products. In order to gain a deeper understanding of composite properties, existing literature led us to select the most important factors. Table 3 shows the production of composites with various compositions.

2.3. Testing of Composite Samples. The ASTM D790 standards were used to prepare and test tensile composite specimens for tensile and flexural strengths. An AG-X Plus machine was used for the tests. Each tensile and flexural test was performed five times, and the average results were recorded. For testing, 5 samples of size 300 × 300 × 3 mm are taken from composites at random. A microhardness tester was used to quantify the hardness of the composite specimens in accordance with the ASTM E 384. The examinations were performed with a 100 g load and a dwell period of 15 seconds. The mechanical characteristics of the produced composites were tested. Two distinct thicknesses of composites, 3 mm and 5 mm, are created and post-cured at room temperature for 10 hours to meet the pre-determined dimensions. ASTM standards were used to characterize the mechanical of the prototypes.

3. Results and Discussion

Experiments conducted in this part demonstrated how MWCNTs, compression molding parameters, and other variables affect hardness, tensile, and bending strength. Compression molding operating parameters, as well as the degree to which each of these process factors affected mechanical performance, were identified using single-factor studies on compression temperature, pressure holding time and pressure.

3.1. Effect of Multiwall Carbon Nanotubes on the Composite Samples. With the use of compression molding, composite samples (neat and hybrid) can be created. Table 4 shows the mean TS of five samples under each testing condition when MWCNT amounts were changed. The tensile characteristics of MWCNT-reinforced composites were found to

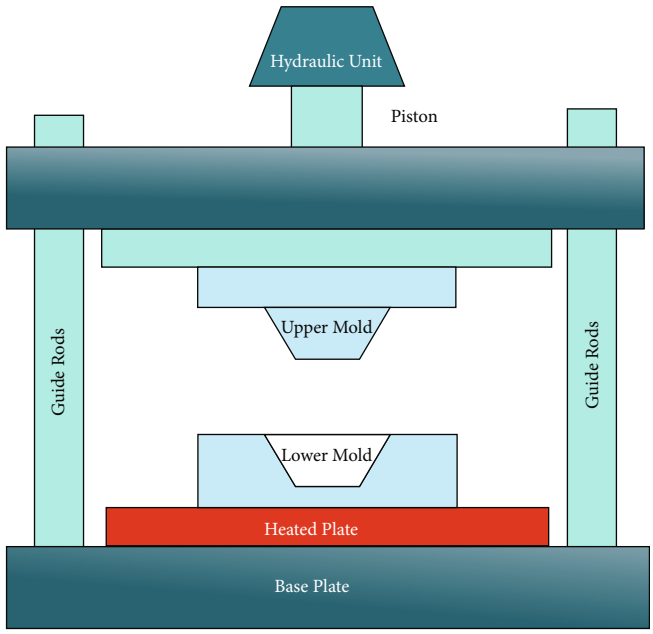

Figure 2: Schematic view of compression molding machine.

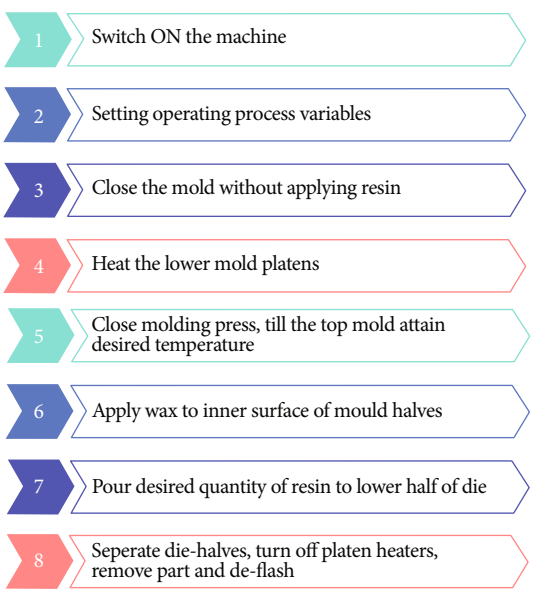

Figure 3: Steps involving the compression molding process for producing hybrid composites.

Table 3: Fabrication of composites.

Type of composites	Sample designation	Weight %		
		MWCNTs	Epoxy	Glass + Kevlar
Neat	NGKEC	0	50	50
	MWCNTKEC	0.4	50	49.60
Hybrid	MWCNTKEC	0.8	50	49.2
	MWCNTKEC	1.2	50	48.8

be superior to those of the unreinforced composites. Adding MWCNTs (nanofillers) prevents crack formation and propagation, allowing the composite to absorb the maximum amount of load until it cracks. There was a drop in tensile strength after adding 0.8 weight percent of MWCNTs to the clean composite, which may be the result of nanofiller agglomeration in the matrix.

Composite samples with 0.8 percent weight of MWCNTs had the highest tensile strengths. This may be because of consistent distribution of MWCNTs between the epoxy matrix and the fiber surface. The gaps in composites increase when MWCNTs nanoparticles exceed the critical weight limit (i.e., 1.2 wt. percent). As a result of the epoxy resin having a higher viscosity, trapped gases or bubbles and volatile impurities may be held back from dissolving and contaminating the finished product. Since the MWCNTs in the epoxy matrix are spread evenly, the fiber and epoxy have better interfacial interaction and interlocking. When comparing a neat composite to a hybrid composite, the hybrid composite has a greater surface area enclosed in stress versus strain area curves, and it is shown in Figure 4. In the MWCNT composites, the MWCNTs serve as crack arresters and bridge the cracks, resulting in a toughening effect.

The hardness variations in composite samples are shown in Table 5. At 1.2 wt. percent of MWCNT, agglomeration causes nanocomposites to be more prone to porosity. Nanotubes in nanocomposites experience axial compression, bending, and buckling as the indenter slides. The following features of MWCNTs contribute to their improved interfacial bonding: One-dimensional nanostructure with a high aspect ratio and a C-C covalent bond directed on axis of CNT improved strength of the material. In nanocomposite, a material's robust network structure provides higher hardness and strength. In contrast, inadequate dispersion can lead to agglomeration and void formation in composites

Table 4: Reinforcement of NGKEC with NEAT and multiwalled carbon nanotubes.

Materials designation	Tensile strength	E_t	Bending strength	E_f
NGKEC	138	3419	105.6	3012
0.4 MWCNTKEC	155	3521	125.1	2009
0.8 MWCNTKEC	183	3942	158.3	8064
1.2 MWCNTKEC	178	3321	114.6	5091

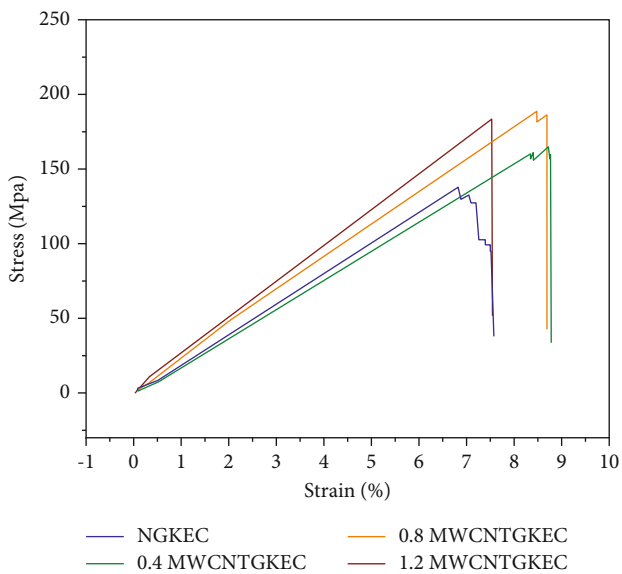

Figure 4: Plot of stress-strain data comparing neat and hybrid composites for tensile strength.

Table 5: Glass/Kevlar/epoxy composites enhanced with NEAT and MWCNT at high hardness.

Material designation	Hardness (HV)
NGKEC	21
0.4 MWCNTKEC	22.1
0.8 MWCNTKEC	23.8
1.2 MWCNTKEC	21.6

when MWCNTs are used in concentrations greater than 0.8%. Consequently, the microhardness of these composites is greater than the microhardness of their neat counterparts.

3.2. Influence of Compression Molding Parameters. The mechanical performance of the compression-molded hybrid composite (0.8MWCNTGKEC) is assessed at a pressure time of 10 minutes and a compression pressure of 20 MPa. Optimized molding temperature settings of 80°C yield the best mechanical qualities, and it is shown in Figure 5. Fiber impregnation is reduced when the epoxy matrix does not fully melt or flow at low mold temperatures. There will be excessive flow viscosity and inadequate saturation if the heating temperature is too low during the molding process because the resin cannot fully melt or flow; if heating temperature is too high, the resin will be degraded and its mechanical performance will be reduced. When a thermoset matrix material has hardened, it can never come back to its original state. This may be due to the formation of cross-links, which are three-dimensional molecule chains. In order for the matrix to be so strong and thermally robust, the curing temperature must be increased. Fibers begin to disorder and epoxy matrix starts to destroy above the critical set mold temperature (>80°C), resulting in brittleness and decreased strength. The findings are in line with previous studies. Using experimental input-output data, the impact of mold temperature was evaluated. The tensile and bending strengths of composites are determined to be 139.87 and 169.88 MPa, respectively, when compression temperatures changed among their corresponding ranges. In hybrid composites, tensile and bending strength increase by 21.46% and 21.26%.

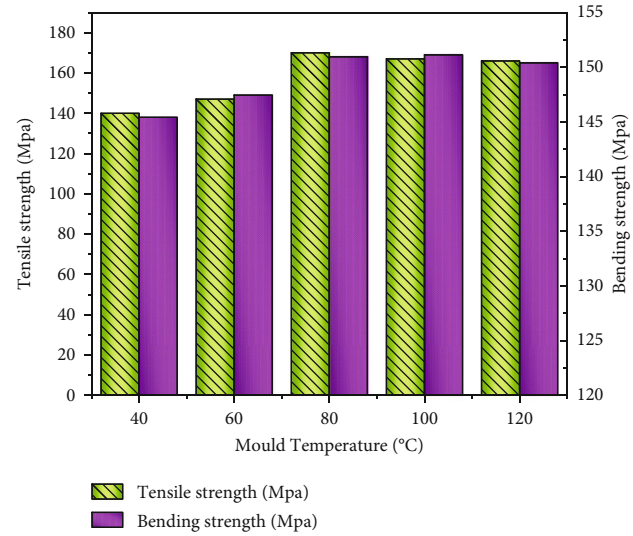

Figure 5: Tensile and bending strength changes with the temperature of the mold.

3.3. Compression Pressure Has an Effect on Tensile and Bending Strength. Hybrid composites are manufactured using pre-set compression molding conditions (0.8MWCNTGKEC) and the effect of compression pressure on mechanical properties.

Figure 6 demonstrates that the tensile and bending strength increases about to 22 MPa at pressure and then stabilizes. To maximize the strength of hybrid composites, compression pressure of 20 MPa should be applied. As the resin impregnation increases, porosity decreases, as does the resin flow and spreading across the fiber surfaces. Fiber structure may be damaged if compression is applied beyond 20 MPa, resulting in lower mechanical strength. With regard to part removal, a high level of compression pressure makes it difficult to separate solidified parts from their mold cavities, notwithstanding shrinkage as a result of cooling and an adequate die design for ease of removal. Compression pressure is examined by altering the pressure within and between the two ranges they occupy. When it comes to composite materials, the low and high tensile strengths are 140

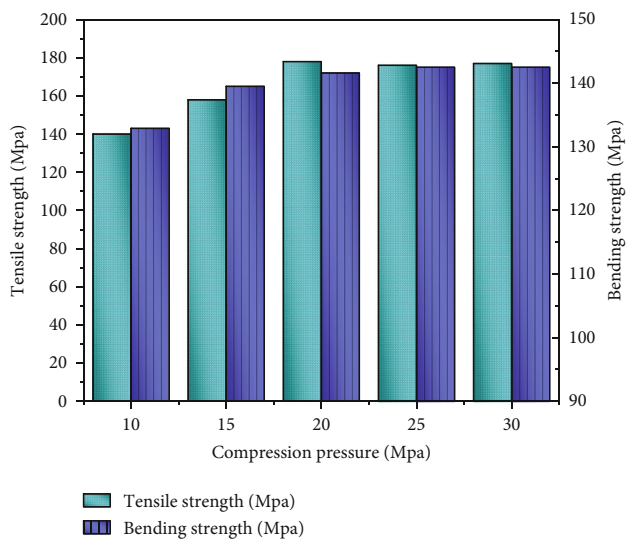

Figure 6: Tensile and bending strength as a result of compression pressure.

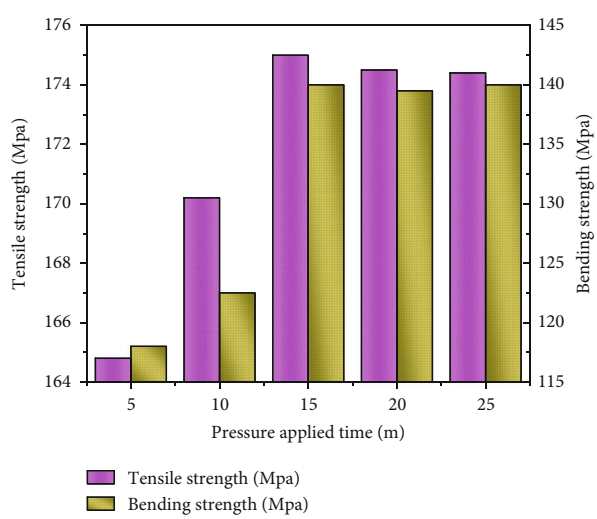

Figure 7: Tensile and bending strength as a function of time applied pressure.

and 178.23 MPa, respectively, while the bending strengths range from 99.23 to 142.32 MPa. In terms of tensile and bending strengths, the hybrid composite caused in a 27.3 percent and 43.42 percent increase in compression pressure, respectively.

3.4. The Tensile and Bending Strength of a Material as a Function of the Amount of Pressure Applied over Time. The mechanical properties of composites are shown in Figure 7 as a function of the amount of pressure applied over time. In order to maintain a consistent compression pressure and mold temperature of 80°C, the experiments must be performed under constant conditions. When pressure is applied for a longer period of time, mechanical strength increases substantially for the first 15 minutes, but after that point, there are no discernible improvements. The fabricated composites may have some voids or porosity if a low compression pressure holding time is used.

Hybrid composites were subjected to a variety of pressure applied times between 5 and 25 minutes. The tensile strength ranges from 165 MPa to 175 MPa, while the bending strength ranges from 120.12 MPa to 136.69 MPa. The localized heat is a mix of the two. When MWCNTs are included in the composite, they enable strong interaction among matrix fibers, resulting in enhanced load transfer as an outcome of the larger aspect ratio and surface area of nanofiller.

4. Conclusions

The mechanical and tribological characteristics of MWCNT reinforced with different fibers and epoxy composites were investigated in this work under the impact of compression molding parameters. The current study discovered that MWCNT reinforced with glass/Kevlar/epoxy composites resulted in composites that were stronger and tougher. 0.8 percent MWCNTGKEC outperformed 0.4% and 1.2% nanofiller additions to a pure composite, respectively. All compression molding factors were shown to have a considerable impact on composite mechanical strengths and hardness. Compression pressure has the biggest influence on composite tensile and bending strength, followed by mold temperature and pressure application duration. In 0.8% CNTGKEC, the hybrid composite had higher tensile strengths of 183 MPa, bending strengths of 158.3 MPa, and hardness of 23.8 HV.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Investigation on Mechanical and Thermal Properties of a Kenaf/Jute Fiber-Reinforced Polyester Hybrid Biocomposite

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This study investigates the mechanical and thermal properties of biocomposite in relation to their hybridization. Compression moulding was utilised to produce hybrid biocomposites composed of polyester resin reinforced with kenaf, jute, and three distinct combinations of kenaf/jute fibers. To increase the bonding of kenaf and jute fibers with polyester resin, a 5 percent NaOH solution was administered to them. The following stacking sequences were used to manufacture a total of five different types of laminates: polyester resin 80 wt%/kenaf fiber 20 wt%, polyester resin 80 wt%/jute fiber 20 wt%), polyester resin 80 wt%/kenaf fiber 5 wt%/jute fiber 15 wt%, polyester resin 80 wt%/kenaf fiber 10 wt%/jute fiber 10 wt%, and polyester resin 80 wt%/kenaf fiber 15 wt%/jute fiber 5 wt%. In the mechanical and thermal tests, it was discovered that the polyester resin 80 wt%/jute fiber 20 wt% biocomposites had increased strength compared to the other hybrid biocomposites investigated.

1. Introduction

A growing demand for alternative raw materials [1] such as wood [2] is being seen in the furniture, automobile, and home industries accordingly of the exhaustion of natural wealth in these industries. Because of its environmentally friendly character, the utilisation of natural fiber as a reinforcement in polymers has expanded in popularity in recent years [3, 4]. Natural fibers are extremely durable, lightweight, and inexpensive when evaluated to synthetic fibers. Scientist has been looking for nonwood bio-based options for composite manufacture in order to meet this need. Several biomaterial-based composites have been proposed by researchers [5, 6] as a viable alternative to synthetic fiber and wood in numerous applications. In the meadow of material development, developing natural fiber-reinforced polymer composites has become a common technique. Material researcher is working on a variety of polymer

composites that make use of readily available natural fiber. Reinforcing starch-based polymers with stronger and additional robust normal cellulose cellulosic fibers is one of the conceivable methods of improving mechanical and thermal qualities [7].

Lignocellulosic fibers have a lower density than synthetic fibers, and they are also totally biodegradable, making them an excellent option to artificial fibers. The use of lignocellulosic fiber reinforcement can also greatly get better the mechanical characteristics of starch-based matrixes [8]. Lignocellulosic fibers such as date palm, sisal, kenaf, jute, wood, banana, cellulose, orange, bagasse, and flax are a few examples of lignocellulosic fibers that have all been deliberate and established to be a useful technique to significantly improve the versatile properties of starch-based matrix [9–11]. In the polymer industry, hybridization has become a widely used technique that allows designers to create products among advanced mechanical properties while minimising the property of humidity absorption as well as reduced fiber/matrix bonding by reinforcing by means of two different natural fibers or natural and artificial fibers [12, 13]. Hybridization's impact on composites' dynamic and thermomechanical properties has been examined in numerous studies.

Some researchers reinforced it with natural, glass, or carbon fibers. This work [14] said that when glass fiber was mixed with oil palm in a phenol-formaldehyde-resin, it made the material stronger, more stable, and less water-absorbing. They [15] say that the mechanical properties of bamboo fiber/glass fiber polymer composites are better than bamboo fiber polymer composites, which are better than bamboo fiber composites. A study [16] found that the glass fiber hybridization had a positive effect on the tensile, flexural, impact, and water absorption properties of the hybrid composites, as well as their strength. At 8.55 wt percent of glass fibers in pine apple leaf fiber-polyester hybrid composites and 5.5 wt percent of glass fibers in sisal fiber-polyester hybrid composites, the ultimate tensile strength and impact strength are at their peak. The thermal and mechanical investigation of biohybrid jute/sisal fiber-reinforced epoxy biocomposites with varying jute/sisal fiber weight ratios revealed that hybridization improved the thermal study of the biocomposites. Additionally, biohybrid composites with a larger jute fiber content had higher storage modulus, loss modulus, and Tg [17].

Kenaf fiber is particularly compatible with polymers, and the matrix will cover the entire surface of the kenaf fiber, improving thermal stability. The combination of PALF and kenaf fiber will advance thermogravimetric, mechanical, and dynamic analysis [18]. Nonetheless, a small number of studies have been conducted with hybrid biocomposites made of a polymer with various forms of kenaf and jute fiber reinforcement. The goal of our research is to manufacture high-class biocomposite product at a little price by utilising natural fibers such as kenaf fiber and jute fiber. Various composite materials, including PR/KF, PR/JF, PR/KJF1, PR/KJF2, and PR/KJF3, are proposed to be created by reinforcing kenaf and jute fibers in various combinations with polyester resin and reinforcing kenaf and jute fibers in various mixtures. Therefore, it is proposed to assess the various properties of each and every biocomposite material, such as mechanical and thermal stability, in order to find the most cost-effective and superior biocomposite among all potential blends.

2. Materials and Experimental Details

2.1. Preparation and NaOH Treatment of Kenaf and Jute Fibers. Kenaf and jute fibers were obtained from the Mayiladuthurai neighbouring bazaar in Tamil Nadu, India. Polyester resin, NaOH, and hardener (HY951) were procured from Vinayaga Scientific, Tiruchirappalli, Tamil Nadu, India. The moisture content of the collected kenaf fiber and jute fiber is being removed by drying. The dried fibers are sliced into 20 mm lengths. NaOH treatment of kenaf fiber and JF fibers was performed first to remove the lignin, wax, and oils from the fibers cell wall's outer surface [19]. A 5 percent solution of NaOH was used to submerge the cleaned and dried kenaf fiber and jute fiber for 24 hours. It was then washed with water and neutralised with weak acetic acid before drying in an oven at 90 degrees Celsius for a period of 18 hours to dry the kenaf fiber and jute fiber. When a hydrophobic polymer matrix encounters a particle, weedy bonding occurs at the particle/matrix contact; hence, this treatment was aimed at boosting outside area while decreasing hydrophilic groups.

2.2. Preparation of Hybrid Biocomposites. Compression moulding was used to create the biocomposite materials used in this investigation. To make the biocomposites, the appropriate amount of kenaf fiber (10 wt percent), jute fiber (10 wt percent), and polyester resin was taken, along by way of the hardener araldite (HY951). In terms of weight, the polymer and hardener are mixed at a 10 : 1 ratio. Only the mixture can be placed after that. A pressure of 120 kgf/cm^2 was gradually applied to the laminate to ensure consistent resin dispersion throughout. It also aids in the removal of trapped air [20]. The samples were held under the same pressure for about 3 hours to achieve complete cure. Table 1 shows a variety of compositions.

2.3. Composite Characterisations. The tensile and flexural test specimens were produced in accordance with ASTM D638 and ASTM D790, correspondingly, and tested at a specific load on a Unitek—94,100 tensile testing machine. The Izod impact test on notched specimen is carried out using an EMIC pendulum machine per ASTM D-256. It weighs 0.6 kg and hits at 3.35 m/s. Sample dimension is $65 \times 13 \times 3$, depth of "V" notch is 2 mm, and angle is 45°. The machine's dial indication indicates the impact energy of various specimens. The impact strength was evaluated using five distinct specimens' mean values. TG was used to measure the thermal strength and thermal degradation of the biocomposite samples. Thermogravimetric analyzer NETZSCH STA 449F3 (JUPITER, Annamalai University) was utilised. Each sample was heated to 600 degree Celsius in a platinum pan at a rate of 5°C/min beneath nitrogen.

Table 1: Composition of biocomposites.

S. no	Sample	Composites	Biocomposites
1.	S1	PR/KF	PR 80 wt%/KF 20 wt%
2.	S2	PR/JF	PR 80 wt%/JF 20 wt%
3.	S3	PR/KJF1	PR 80 wt%/KF 5 wt%/JF 15 wt%
4.	S4	PR/KJF2	PR 80 wt%/KF 10 wt%/JF 10 wt%
5.	S5	PR/KJF3	PR 80 wt%/KF 15 wt%/JF 5 wt%

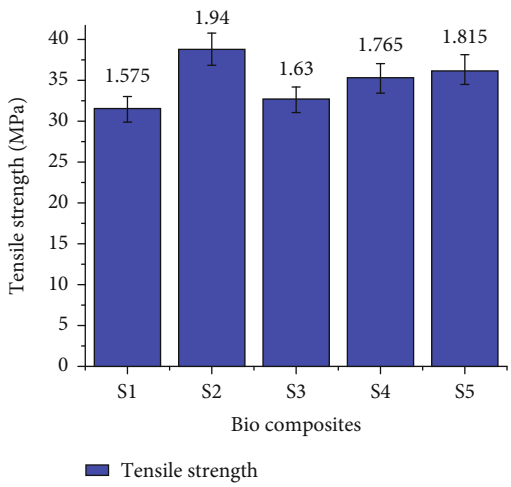

Figure 1: Variations of tensile strength with KF/JF fiber biocomposites.

3. Results and Discussion

3.1. Tensile Strength. Figure 1 depicts the achieved tensile strength on hybrid biocomposites as a function of kenaf fiber, jute fiber, and KJF reinforcement. The pattern clearly demonstrates an increase in tensile strength for kenaf fiber and JF reinforcement. Tensile strengths were 31.5, 38.8, 32.6, 35.3, and 36.3 MPa for PR/KF, PR/JF, PR/KJF1, PR/KJF2, and PR/KJF3 biocomposites, respectively. The highest tensile strength obtained in PR/JF (38.1 MPa) biocomposite is further evaluated to hybrid biocomposites PR/KJF1, PR/KJF2, and PR/KJF3. This might be attributed to the complement behaviour of two or more fibers in the hybrid composite, whereas jute fiber in the PR/JF biocomposite imparts higher tensile strength [21]. As a result, by correct material design, a balance of performance and cost might be achieved.

3.2. Flexural Strength. Figure 2 illustrates the flexural strength of PR/KF, PR/JF, PR/KJF1, PR/KJF2, and PR/KJF3 natural fiber-reinforced biocomposites. It had greater values than the biocomposites' tensile strength, which might be attributable to the fiber orientation in the biocomposites' outer layer. A similar pattern emerged in this finding as well; the PR/JF biocomposite had the highest flexural strength (78.90 MPa) when compared to the other biomaterials (PR/KF, PR/KJF1, PR/KJF2, and PR/KJF3 materials). As a result, polyester may bond effectively to jute fibers, resulting in excellent flexural strength [22].

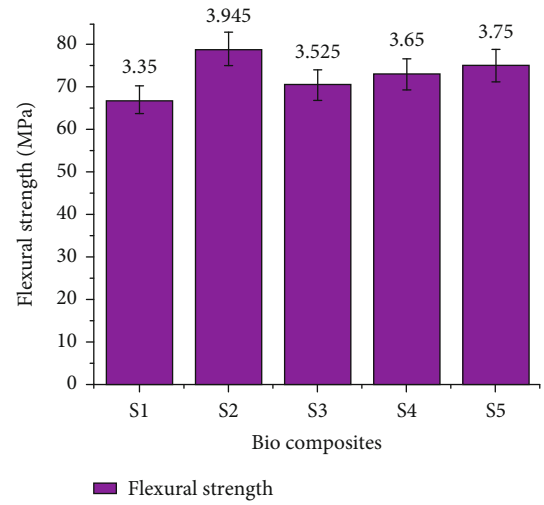

Figure 2: Variations of flexural strength with KF/JF fiber biocomposites.

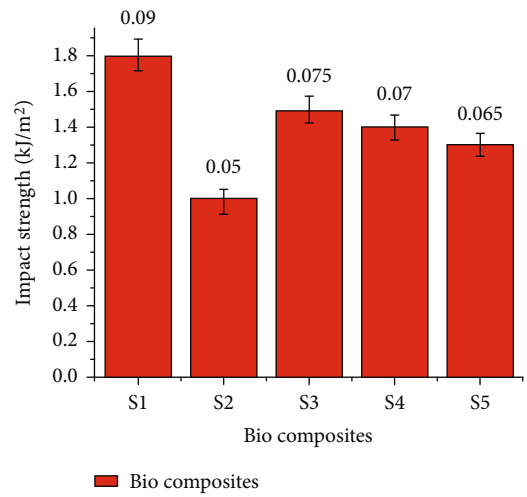

Figure 3: Variations of impact strength with KF/JF fiber biocomposites.

3.3. Impact Strength. This result followed the same pattern as tensile and flexural strength; Figure 3 shows the impact strength variation with PR/KF, PR/JF, PR/KJF1, PR/KJF2, and PR/KJF3 fiber reinforcement. Figure 4 shows that the capacity to oppose impact force is stronger in the biocomposite reinforced among PR/KF (1.8 kJ/m2) than in biocomposites reinforced with further fibers since the fibers contributed a little brittleness as a result of increased hardness, which resulted in a drop in impact strength. This highest in impact strength reflects the fiber's involvement and the biocomposites' capacity to absorb energy. This is appropriate to the fiber and matrix's strong interfacial bonding [23]. It furthermore depends on the characteristics of the fiber and resin.

3.4. Flexural Fracture Surface Morphology Evaluation. Figures 4(a)–4(c) represent the flexural fractured surface on PR/KF, PR/JF, and PR/KJF2 biocomposites. Figure 4(a) shows a SEM picture of the PR/KF biocomposite, which

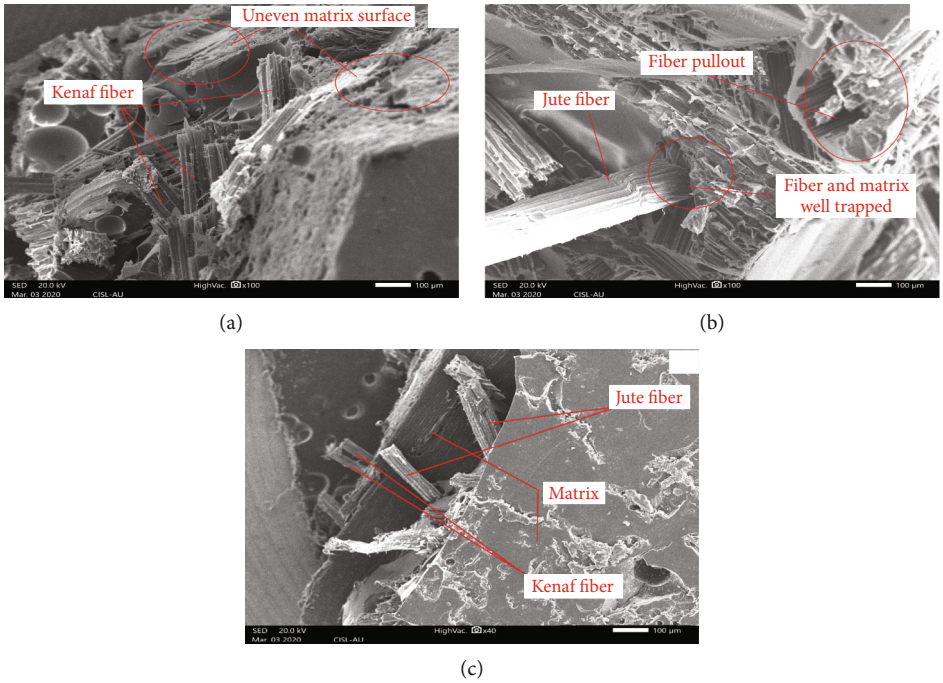

Figure 4: SEM image of a biocomposite fracture surface of flexural strength, for (a) PR/KF, (b) PR/JF, and (c) PR/KJF2.

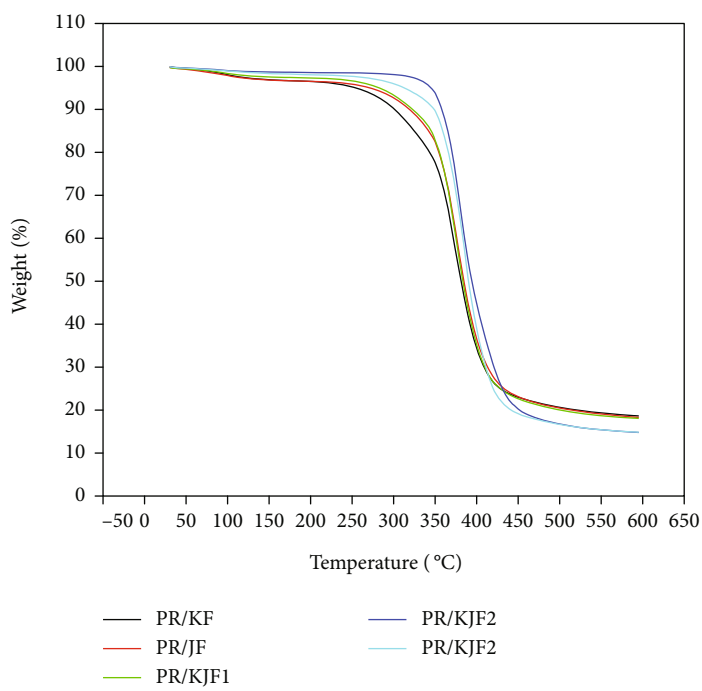

Figure 5: TGA curves for KF and JF biocomposites.

clearly displays the kenaf fiber and the poor interfacial bonding between the kenaf fiber and the resin [24]. Figure 4(b) shows an irregularly broken pattern in the PR/JF sample, indicating an interfacial zone between jute fiber and resin. Well-trapped fiber, lack of fiber cohesion, lack of voids, and good adhesion to the fiber-matrix interface characterise this material. It helps PR/JF (38.1 MPa) biocomposites have superior flexural strength. The flexural fractured surface of the PR/KJF2 biocomposite, which contains kenaf and jute fiber, is shown in Figure 4(c) as a series of small holes. As a result, the crack propagation is lengthened [25, 26].

3.5. Thermogravimetric Analysis (TGA). Figure 5 illustrates the outcome of the thermogravimetric analysis of all the PR/KF, PR/JF, PR/KJF1, PR/KJF2, and PR/KJF3 samples in the temperature variation of 0–600 degree Celsius in

nitrogen atmosphere. The PR/JF biocomposites showed much greater thermal stability than the other four biocomposites, as shown in Figure 5. Thermogravimetric analysis is widely used to identify materials that have lost or gained mass owing to breakdown, oxidation, or the loss of volatiles. The first weight loss (9.2%) among 50 and 340 degree Celsius relates to the evaporation of absorbed moisture comfortable starting the biocomposites, as seen by the thermogravimetric analysis curve. The most major components of hemicelluloses, cellulose, and lignin are accountable for the drastic weight loss from 340 to 455 degree Celsius. Total weight losses of PR/KF, PR/JF, PR/KJF1, PR/KJF2, and PR/KJF3 biocomposites were 84.2, 81.4, 83.6, 86, and 87 wt percent, respectively, after decomposition. When compared to other composites, PR/JF had the smallest weight reduction (81.4%). Jute fiber has a much greater experimental thermal stability than the other four biocomposites mentioned in the literature [27, 28]. This indicates that the PR/JF composite had a high amount of fiber integration.

4. Conclusion

This study looked at the mechanical characteristics and thermal strength of polyester biocomposites reinforced with kenaf fiber and jute fiber. The evidence and discussion presented above led to the following conclusions.

(i) The PR/JF biocomposite outperforms the other four biocomposites in terms of mechanical strength, such as tensile and flexural strength

(ii) Also, PR/JF biocomposite demonstrated greater thermal stability and temperature degradation than other biocomposites, according to thermogravimetric analysis

(iii) In tensile strength, PR/JF biocomposite attained maximum tensile strength (38.1 MPa)

(iv) In flexural strength, PR/JF biocomposite had the highest flexural strength (78.90 MPa)

(v) Lastly, the impact strength PR/JF biocomposite reinforced among PR/KF (1.8 kJ/m^2)

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Water Absorption Behavior of Teff (*Eragrostis tef*) Straw Fiber-Reinforced Epoxy Composite: RSM-Based Statistical Modeling and Kinetic Analysis

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Recently, reinforced polymeric composites prepared from natural fibers have received a significant interest among the researchers because of its appreciable sustainability, environmentally friendly, and low cost. However, one particular issue, that is, hydrophilic property, still needs to be addressed for its successful applications. Since the hydrophilic tendency of natural fibers is extremely undesirable, it leads to the quick degradation of fiber-based polymer composites. Hence, the fiber property, hydrophilic nature, is influenced by the presence of noncrystalline and voids part of these fibers that significantly influences the polymer matrix adhesion. Hence, it is very important to understand the water absorption behavior of reinforced fiber composites. In this study, a crop residual material specific to Ethiopia, teff straw (*Eragrostis tef*), was used as fiber material. The fiber was treated with 1% NaOH followed by 1% CH_2=CHCOOH at room temperature for improving the bonding strength between the fiber and polymer, which leads to suppress the water absorption. The investigation on mathematical model for water absorption property at different fiber loadings (4%, 8%, 12%, 16, and 20%) was carried out, and the analysis on the kinetic behavior of water absorption was also investigated. In addition, the response surface-based statistical modeling which correlates water absorption, fiber loading, and time has been analyzed.

1. Introduction

In recent days, a significant awareness has been increased to look for the materials not only with excellent properties but also having appreciable sustainability with economically feasible [1]. Commercially, the cellulosic fibrous feedstocks are used as major raw materials to prepare reinforced polymer matrixes for the development of composite materials which are derived from both woody and nonwoody sources. Woody supplies are collected from forests, whereas nonwoody sources are obtained from sources other than forests, such as recycled fibers, sugarcane bagasse, nonwoody plant straws, rice husk, agroindustrial byproducts, and agricultural leftovers. In order to overcome the environmental issues from deforestation, nonwoody raw materials are gaining the huge interests for production of fiber pulps in composite

material sectors since they have several benefits of being readily grown, high growth rate, comparatively high cellulose content, a low amount of lignin, high volume generation in modern irrigation, and requirement of small amount of fertilizer for mass production [2]. Undeniably, the approach with respect to the smart use of full natural resources with integrated multiproduct valorization is always most welcomed. Under this concept, the study of underutilized resources, including residues and by-products from existing nonwoody crops, attain a renewed interest for fibrous production. In elsewhere, different natural fibers such as wheat straw, bagasse, jute, and pineapple were investigated to be used as reinforcement in polymer matrix.

Teff hay or straw is hard stem part of the teff plant which is known to be an indigenous lignocellulose biomass. In Ethiopia, teff crop is cultivated most extensively. At present, a significant volume of teff and its straw is produced annually in different provinces of Ethiopia. It is well-known cereal crop culverted and staple food in Ethiopia. Hence, teff straw is most widely available in almost all agricultural places of Ethiopia. Once the grains of teff seeds were separated, the teff straw was considered an agrowaste. Lot of researches were carried out in terms of beneficial utilization of teff straw. Earlier, teff straw was investigated by Devnani and Sinha [3] to develop a light-weight composites reinforced by epoxy. In another study, Abraham has examined on the mechanical properties reinforced concrete made by the teff straw [4]. However, still there is a room for research on the use of teff (*Eragrostis tef*) straw- (TS-) based-reinforced polymeric composite materials. Teff is one of Ethiopia's most well-known indigenous crops; once the seeds are harvested from the crop, a significant volume of TS from post-harvest is obtained as agricultural residue. Hence, TS is widely available, inexpensive, and most abundant in Ethiopia [5]. TS is the dry stalks part of teff hay. The studies on chemical composition of TS revealed that it composed with 37.1% cellulose content, 28.99% hemicellulose, 17.85% lignin, and 8.55% extractives. Such a substantial amount of cellulosic and hemicellulosic contents makes that the TS can be a potential feedstock for natural fiber-based polymeric composite materials.

From the previous studies, it was observed that one particular issue, that is, the compatibility between the hydrophobic nature of the polymer matrix and hydrophilic nature of the natural fibers, is the responsible factors for unsatisfied mechanical and thermal properties of polymeric composite materials. Various researches were carried with different treatment methods to attain an improved quality of composites towards abovementioned issue. Keeping this view, a most important behavior of composite materials, water absorption, can be an imperative aspect to produce a superior quality composite [6, 7].

In the present study, a crop residual material, TS, was used as fiber feedstock to prepare a composite material. The fiber was treated with NaOH followed by acrylic acid at room temperature for improving the bonding strength between the fiber and polymer and to suppress the water absorption. The investigation on mathematical model for water absorption property at different fiber loadings was carried out. The kinetic analysis on water absorption was also established. In addition, the response surface-based statistical modeling which correlates water absorption, fiber loading, and time has been analyzed. In order to get the interaction between water absorption and fiber loading, an emphasis has been given for statistical modeling using response surface methodology (RSM) with aim of appropriate valorization of the TS towards reinforced polymeric composite production.

2. Materials and Methods

2.1. Teff Straw and Chemicals. Teff straw (TS) was collected from the nearby agriculture province of Addis Ababa, Ethiopia. The TS was chopped by manually to have the average length of TS 5-10 mm. Further, it was washed thoroughly using distilled water to remove unwanted waste impurities and soil debris. Then, it was subjected to dry using hot air oven for 48 h at 650°C. This material was named as untreated TS fiber; hereafter, the same is called as UTSF [8]. A standard epoxy resin (AW106) and hardener as curing agent (HV953IN) were obtained from Mexico Araldite Pvt. Limited Addis Ababa, Ethiopia. NaOH was procured JIGRA ETH Chemicals Pvt. Limited, Addis Ababa, Ethiopia. Acrylic acid was obtained from AE Chemicals Trading Plc. Pvt. Limited, Addis Ababa, Ethiopia.

2.2. Surface Treatment of TS Fibers. Clean TS fibers were under taken to soak in 1% NaOH for 45 min followed by 1% acrylic acid for 45 min. This treatment was carried out at room temperature. The treatment was carried out at ratio of 20 : 1 for the liquor to fiber. Further, the treated TS fibers were again washed thoroughly using distilled water for removing the remaining chemicals that used for surface treatment. Then, treated TS fibers kept in hot air oven (75°C for 48 h) to dry by removing the moisture. These fibers were named as TTSF and considered as treated TS fibers [9].

2.3. Preparation of UTSF and TTSF Composites. As per the recommendation from the supplier, the hardener and epoxy resin were mixed in the ratio of 4 : 5. Then, UTSF and TTSF were mixed separately to prepare the reinforced polymeric composites. Each mixture was stirred using mechanical agitator at 1800 rpm for 15 min. The mixture was observed to be uniform and homogeneous. Further, the mixture was poured in a mold with the size having $250 \times 250 \times 10\,\text{mm}^3$. Then, it was allowed to cure at room temperature for 24 h. For the fabrication purpose, hand layup technique was carried out to prepare the composites obtained from UTSF and TTSF. In order to avoid sticking of epoxy fiber mixture to the wall of the mould, a clean polythene sheet was used [10]. A dead weight of 20 kg was kept on the mould for two days. The composites were carefully withdrawn from the mould for water absorption test. From the results, it was apparent that the composite prepared from TTSF had lowered water absorption. Hence, further water absorption analysis has undertaken with different fiber loadings using TTSF. Abovementioned composite preparation technique was used for different fiber loadings (4%, 8%, 12%, 16, and

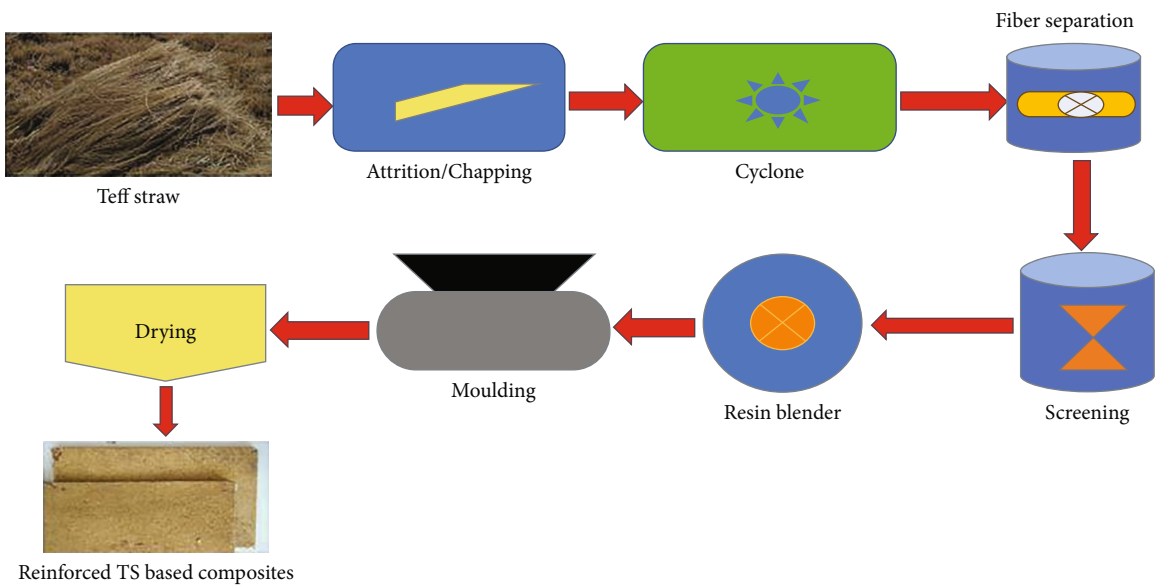

Figure 1: Schematic flow of TS-based composite preparation.

20%) of TTSF. Further, they were subjected to water absorption test. The schematic flow of TS-based composite preparation is presented in Figure 1.

2.4. Water Absorption Test. The standard method, ASTM D570, was adopted to analyze the water absorption of TTSF epoxy composites. For that, a sample with 25.4 × 76.2 mm thickness by the wide of composite material was taken [11]. Water absorption of composite was determined using Equation (1).

$$W(\%) = \frac{M - N}{N} \times 100. \quad (1)$$

In Equation (1), M refers the dry initial weight of the sample. N denotes the weight of the sample after immersion in distilled water. W is water absorption rate in percent.

2.5. Kinetic Approach for Water Absorption Behavior. The studies showed that the water absorption in polymer composites can be explained based on Fickian as well as non Fickian concept [12]. While dealing the water absorption behavior on polymer composite, the diffusion coefficient should be considered which is the most important criterion. Diffusion coefficient is defined as the ability of penetration of the water molecules to inside the any sample structure. In order to understand the diffusion behavior, Equation (2) can be used.

$$F = \frac{mt}{mx} = kt^n. \quad (2)$$

In Equation (2), F refers the water absorption in percentage at time any time "t," and "mt' denotes the maximum % of water that can be absorbed. The constants, n and k, are known to be kinetic constants which are useful to understand the water absorption behaviors. By applying the natural logarithm for Equation (2), the resulted equation can be presented as Equation (3).

$$\log F = \log\left(\frac{mt}{mx}\right) = \log k + n \log(t). \quad (3)$$

From Equation (3), a plot, log (F) vs. log (t), was generated which gives the value of n and k using statistical analysis. The n value provides the insight of the diffusion behavior. Accordingly, if the n value is 0.5, the diffusion can be called Fickian mechanism [13]. If the n value is less that 0.5 but close to 0.5, the diffusion can be classified as pseudo-Fickian mechanism. Furthermore, diffusion coefficient (D) was calculated using the following correlation (4).

$$F = \left(\frac{4}{n}\right)\left(D^{0.5}\frac{t^{0.5}}{n^{0.5}}\right). \quad (4)$$

2.6. RSM Statistical Modeling and Analysis. The two independent factors, fiber loadings and time, were under taken for further statistical modeling to correlate the water absorption behavior using response surface method (RSM) through CCD. Table 1 presents the rage of the factors used in this study.

In this study, the Design-Expert® (version 12.0.0) software was employed for CCD combination of experiments and RSM optimization [14]. The sequence of experimental run was undertaken in randomized in order to minimize the effects of the uncontrolled factors. The factors were correlated using a quadratic model. This quadratic model is presented in Equation (4):

$$WA = L_0 + \sum_{j=1}^{2} L_j P_j + \sum_{j=1}^{2} L_{jj} P_j^2 + \sum_{i} \sum_{<j=2}^{2} L_{ji} L_i L_j + s_i. \quad (5)$$

Table 1: The rage of the factors used in this study.

Name of the factor	Minimum	Maximum	Coded low	Coded high	Mean	Std. Dev.
TS loading	1.89	23.11	-1	+1	12.50	6.12
Time	1.59	4.41	-1	+1	3.00	0.8165

Table 2: Parameter values for TTSF-reinforced epoxy composites with different fiber loadings.

Sl No.	Fiber loading	n	k	$D \times 10^{12}$ (m^2/s)
1	4%	0.3123	-0.73631	3.47
2	8%	0.4314	-0.9871	4.71
3	12%	0.4184	-1.0627	5.45
4	16%	0.3572	-0.8126	6.82
5	20%	0.3265	-0.8542	7.32

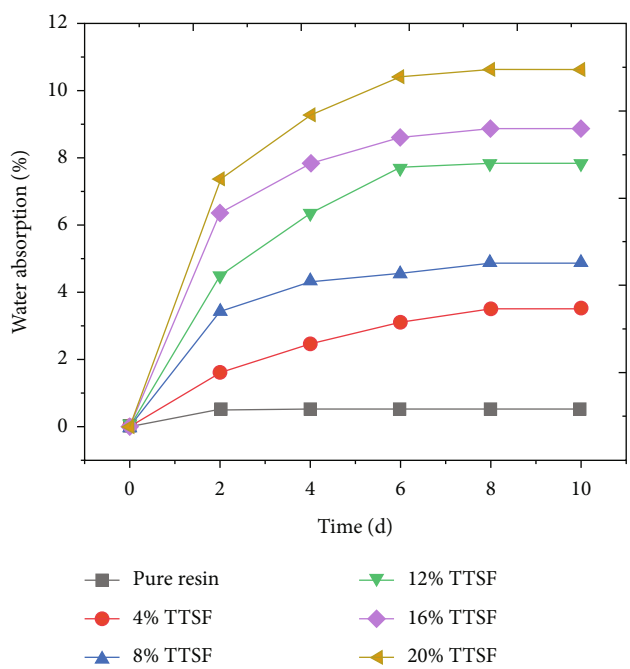

Figure 2: The influence of TTSF loading on water absorption for reinforced epoxy composites.

In the present study, there were 13 runs of experimental plan (Table 2). The water absorption was fed as the response for each combination which was taken as the mean value of duplicate. The results obtained from the 13 combinations of runs were used to fit the model for developing the interrelationship between the fiber loading and time [15]. The model developed by RSM was investigated to check the statistical significance using the ANOVA methodology.

3. Results and Discussions

3.1. Influence of Fiber Loading on Water Absorption and Kinetics. In order to understand the properties of the composite materials, water absorption should be considered seriously [16]. Prior to the experiments, different TTSF loading range was examined. Using these results, it was observed that the range of TTSF varied from 4 to 20%. In the present study, fiber (TTSF) loading was varied (4%, 8%, 12%, 16, and 20%) at fixed level of hardener and epoxy resin. Based on the water absorption property, Figure 2 was constructed which illustrates the water absorbed (%) by the TTSF-reinforced composite material at different fiber loadings. From the results, it was observed that the composites showed higher percent of water absorption compared to pure epoxy resin. The trend of water absorption seemed to be increased with fiber loading [17, 18].

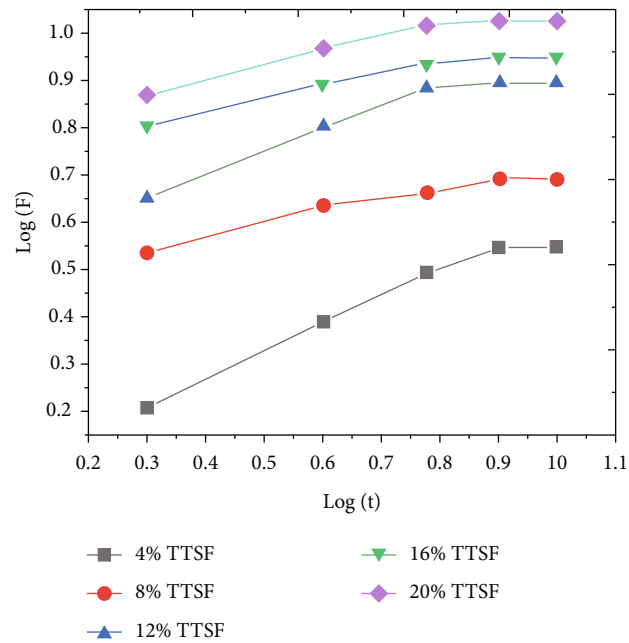

Figure 3: The kinetic plot for water absorption on different TTSF fiber loadings of reinforced epoxy composites.

Figure 3 presents the fitting of experimental data to Equation (3) as kinetic analysis. From the best fit plot, the value of k and n for the TSSF-reinforced composites with different fiber loadings is given in Table 1. From the results (Table 2), it is apparent that TTSF composites follow the mechanism of pseudo-Fickian diffusion. It was observed that n value for all the fiber loadings was close to 0.5. From such a mechanism of pseudo-Fickian diffusion, it is cleared that rate of water diffusion is comparatively less than polymer segment mobility. Thus, equilibrium in polymer can be achieved rapidly. The diffusivity values for the TTSF were observed to be low that explicates that the water absorption

Table 3: CCD matrix and corresponding water absorption for RSM.

Run	TS loading (%)	Time (d)	Water absorption (%)
1	5	2	2.1
2	5	4	2.8
3	12.5	3	4.6
4	12.5	3	4.62
5	1.893398	3	1.2
6	12.5	3	4.6
7	20	4	9.1
8	12.5	3	4.63
9	12.5	4.414214	5.36
10	20	2	7.12
11	12.5	1.585786	4.6
12	23.1066	3	10.23
13	12.5	3	4.63

Table 4: The fit summary of different type of equations.

Source	Sequential p value	Lack of fit p value	Adjusted R^2	Predicted R^2
Linear	<0.0001	<0.0001	0.9639	0.9449
2FI	0.2716	<0.0001	0.9652	0.9414
Quadratic	<0.0001	0.0036	0.9996	0.9983 (suggested)
Cubic	0.0006	0.5228	1	0.9999 (aliased)

is getting lowered while TS has been subjected to treated. The similar observations were found by Li et al. [12] and Japić et al. [9].

3.2. RSM Analysis and Statistical Modeling. As we know, CCD and the BBD are the most widely used designs for the RSM experiment. In this experiment, the two most important parameters only have been taken for the investigation of interaction effects and optimization. Keeping this view, CCD experimental design only can be applicable for the response optimization. Hence, CCD has been considered. Using the RSM coupled with CCD (Table 3), the experimental results were adopted to develop model of equation to correlate the TTSF loading and time. In order to select the most suitable model of equation, the fit analysis on different equations has been carried out; the same is presented in Table 4 as fit summary. In this context, quadratic model was picked out for further response surface analysis. Accordingly, Equation (4) was developed. Based on the model development, response surface was generated with respect to TSSF loading and time; the same is presented in Figure 4. From the interactive analysis, it was cleared that the increasing TSSF led to increasing the water absorption tendency. Also, it was well apparent that the water absorption of prepared TTSF composite materials increased with increasing time. The interaction effect of TSSF loading and time showed a positive effect with the coefficient value, 0.060284 (Equation (4)). However, the p value for the interactive effect was observed to be less than 0.05, which exhibited a potential significance of the adsorption process.

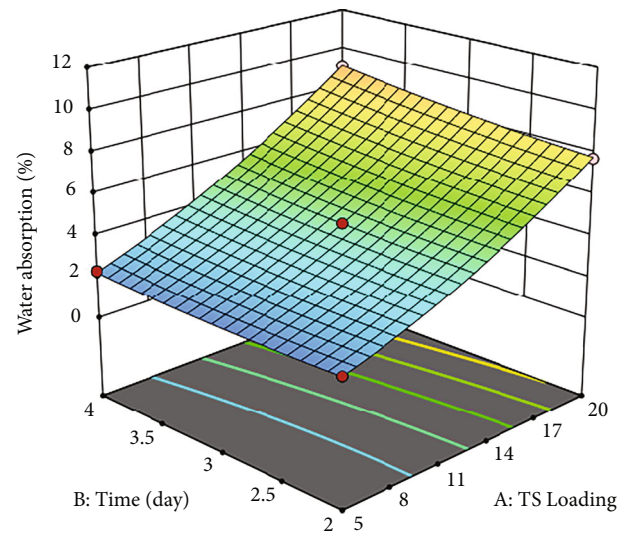

Figure 4: The 3D interactive effect of water absorption with respect to tome and TS fiber loading.

$$\begin{aligned}\text{Water absoption}(\%) = {} & +2.52878 + 0.060284(\text{TS loading}) \\ & - 0.969264(\text{time}) \\ & + 0.038333(\text{TS loading})(\text{time}) \\ & + 0.009802\,(\text{TS loading})^2 \\ & + 0.141375\,(\text{time})^2.\end{aligned} \tag{6}$$

4. Conclusion

The present study describes the influence of fiber loading on the water absorption property for the epoxy-reinforced polymer composite. Teff straw-based polymer composite was developed with different fiber loadings. It was observed that the chemical treated by NaOH followed by acrylic acid explicated less water absorption. Also, the experimental results showed that as TTSF increases, water absorption also increases. The kinetic analysis on the water absorption property revealed that the diffusion curve fitted well the pseudo-Fickian mechanism. In addition, the diffusivities were determined from the different fiber loadings. Further, the RSM-based statistical model was developed with respect to the CCD design, which gives the understandings of the interaction between the fiber loading and time for water absorption.

Data Availability

The underlying data supporting the results of this study were included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Investigation of Curing Mechanism and Mechanical Properties of Polypropylene/Aliphatic Epoxy Composites

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Temperature-sensitive cure kinetics based on bisphenol A oligomeric diglycidyl ether and branching diphenylmethane di-isocyanate, polymer aliphatic or lower molecular weight aromatic amines, and polypropylene and epoxy composites were examined. Polypropylene networks are formed initially, followed by amine hardeners interfering with epoxy oxirane rings to frame linear oligomers. Finally, the system is formed by a reaction between amines obtained in the second phase and epoxy oxirane rings during the curing step. This three-stage treatment was illustrated. The activation energy was calculated using the Flynn-Wall-Ozawa and Kissinger-Akahira-Sunose isoconversational approaches to cure degree. The Ea-to-α correlation was determined using these approaches, revealing that the research curing systems exhibited autocatalytic effects. Among the materials studied, compounds with low molecular weight aromatic amines had the strongest and longest-lasting tensile characteristics. There are numerous advantages to slow curing and discrete stages of composite creation, including better mechanical properties.

1. Introduction

Epoxy resins are both fast-setting thermosets and composite matrices [1]. The aircraft and maritime industries, electronics, coatings, and glues all use them. Thermal, mechanical, and dielectric qualities, as well as a confrontation with erosion and less contraction upon cure, are critical in the applications mentioned above [2, 3]. However, despite their improved hardness, they are still considered rigid and brittle materials, which presents a challenge. The fracture toughness of epoxies can be improved by adding a second phase to remedy this problem [4–6]. Curing is vital for developing strength and

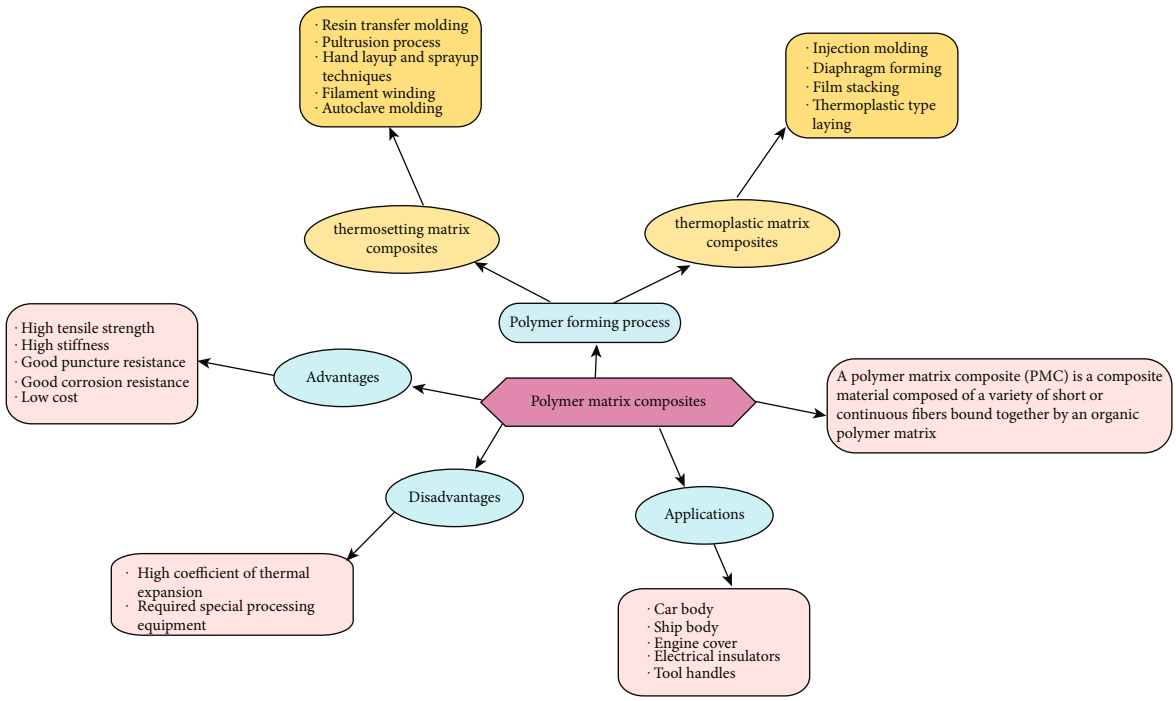

Figure 1: Schematic diagram of polymer matrix composite advantages and applications.

durability, as well as controlling the reaction rate and determining performance parameters. According to research, a secondary phase may include utilizing various polymers [7]. With polypropylene's excellent material qualities (good thermostability, high mechanical and adhesive strength, and strong corrosion and weather and chemical resistance), we considered it to be an exciting alternative in our quest to produce a toughening epoxy [8, 9]. Linear polypropylene has also been successfully used for curing epoxy [10]. Customized thermoset cure kinetics are crucial to both process development and quality assurance. As part of our research, we hope to confirm the relationship between temperature, time, and conversion while also developing a function to describe reaction rates [11, 12].

Consequently, epoxy and polypropylene are the primary focus of this investigation. The cross-linker's efficiency was tested using differential scanning calorimetry (DSC). As amine hardeners, various nucleophilicity and molecular weight and branching architecture were considered while formulating the compounds [13, 14]. Due to the many competing reactions during polypropylene's cross-linking kinetics, we tested a variety of kinetic models. Such a kinetic investigation is ideally suited for differential scanning calorimetry [15, 16]. Such a time and temperature-based optimization of reaction conversion would greatly assist in designing the epoxy's toughness. Figure 1 reveals the schematic diagram of polymer matrix composite advantages and applications.

2. Experimental Part

2.1. Differential Scanning Calorimetry Analysis. Specified amounts of epoxy polyethylene glycol-400, PIC-200, and polyamine hardener were combined at room temperature according to Table 1 requirements. Polyethylene glycol-400 was first dissolved into an equal amount of epoxy and then blended evenly. As a final step, PIC-200 and hardener were mixed together until the resin was utterly homogeneous before being added in order. To determine the kinetics of the drug, we took 20–25 mg samples. Over a temperature range of 25–200°C, a Q600 thermal instrument was used to conduct dynamic differential scanning calorimetry measurements. Onset, peak, and endset temperatures of the exothermic curing reaction, as well as its total heat, were all measured. The responses' precision was utilized in a similar quantity (20–25 mg) for each experiment.

2.2. Preparation of Sample for a Performance Analysis. One-pot approaches were used to make epoxy-polypropylene composites. It was necessary to conduct this polymerization reaction in an apparatus containing a nitrogen intake pipe, thermometer, and mechanical stirrer measuring 500 mL. It was stirred for 30 minutes at room temperature in the mandatory epoxy and polyethylene glycol-400. It took 12 hours of gradual injection at room temperature to add the correct amount of PIC-200 needed. Prepolymer was created by raising the response temperature to 60°C and stirring the reaction for one hour. The amine hardener was added after allowing the reaction mixture to settle to room temperature. A homogeneous mixture was drawn into specific forms to obtain mechanical testing samples. The Universal Testing Machine, as in Figure 2, was utilized to assess the tensile strength and elongation at the break of specimens with proportions of $0.1 \times 0.01 \times 0.00035$ m. Each composition features at least five simple harmonies.

Table 1: Masses of different compositions of polyethylene polyamine.

Samples	Diglycidyl ether of bisphenol A	Polyethylene glycol-400	PIC-200	Polyethylene polyamine
100-0 polyethylene polyamine	100	0	0	13
95-5 polyethylene polyamine	95	5	3.34	12.3
90-10 polyethylene polyamine	90	10	6.68	11.7
85-15 polyethylene polyamine	85	15	10.02	11.1
80-20 polyethylene polyamine	80	20	13.36	10.4

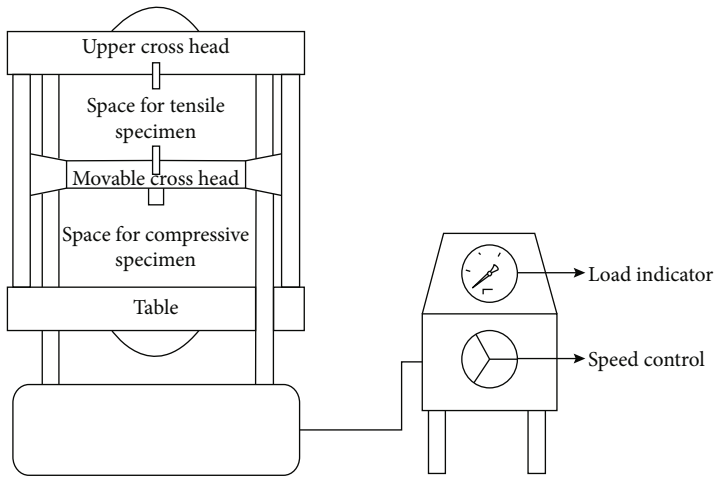

Figure 2: Schematic view of Universal Testing Machine.

3. Results and Discussion

3.1. The Cure Kinetics. At varying heating speeds, a dynamic differential scanning calorimetry curve is indicated in Figure 3. The differential scanning calorimetry readings show that the cross-linking processes are exothermic from start to finish. Table 2 contains the values for these variables. The polypropylene/epoxy mixture's cross-linking approach is multifaceted and involves several conflicting reactions. Because of this, we opted to define the curing response as single kinetic progress as the first calculation, even though differential scanning calorimetry curves show just one shared exothermic peak.

The reactivity of the precursors determines the reaction's starting temperature, whereas the reaction's length determines the process' end temperature [17]. Branching agents are particularly effective in curing epoxy-polypropylene systems [18]. Aromatic amines have a lower nucleophilicity than aliphatic amines, influencing their interactions with the epoxy and isocyanate groups.

A variety of kinetic equations govern the polyurethane/epoxy mixture's healing procedure, which is complex in and of itself. The precise concentration of the reactants can be challenging to determine in many cases. The validity of phenomenological models has been demonstrated in such circumstances [19, 20]. To accurately quantify the quantity of heat emitted, differential scanning calorimetry measurements are necessary. To link the produced heat with the reaction rate, the area beneath each curve is considered directly proportional to the degree of conversion [21]. Heat transfer can be expressed as a percentage of total heat transfer at complete transformation at the given time. The following is the formula for calculating the degree of conversion:

$$\alpha = \frac{1}{\Delta H_0}\int_0^t \left(\frac{dH}{dt}\right) dt, \qquad \frac{d\alpha}{dt} = \frac{dH}{dt \cdot \Delta H_0}. \tag{1}$$

Figure 4 depicts the relationship between heating rate and degree of conversion. As you can see, there is a clear correlation. At whatever rate of heating, the entire conversion occurs. Figure 5 depicts the relationships between the rate of curing response and the degree of cure. The heating rate accelerates the curing reaction. At an extreme response rate, the cure degree essentially remains the same, but the cure degree for systems treated with PPA is shifted to smaller. Researchers employed oligomeric epoxy resins with secondary hydroxyl groups in our investigation. When polyethylene glycol-400 and isocyanate are combined with epoxy, hydroxyl groups' reactivity to isocyanate groups is significantly more potent than the amines' reaction with oxirane rings. In this case, PIC200 has shallow molecular weight differences from polyethylene glycol-400. Linear polymers are formed by epoxy hardener and amine hardener, as depicted in the picture

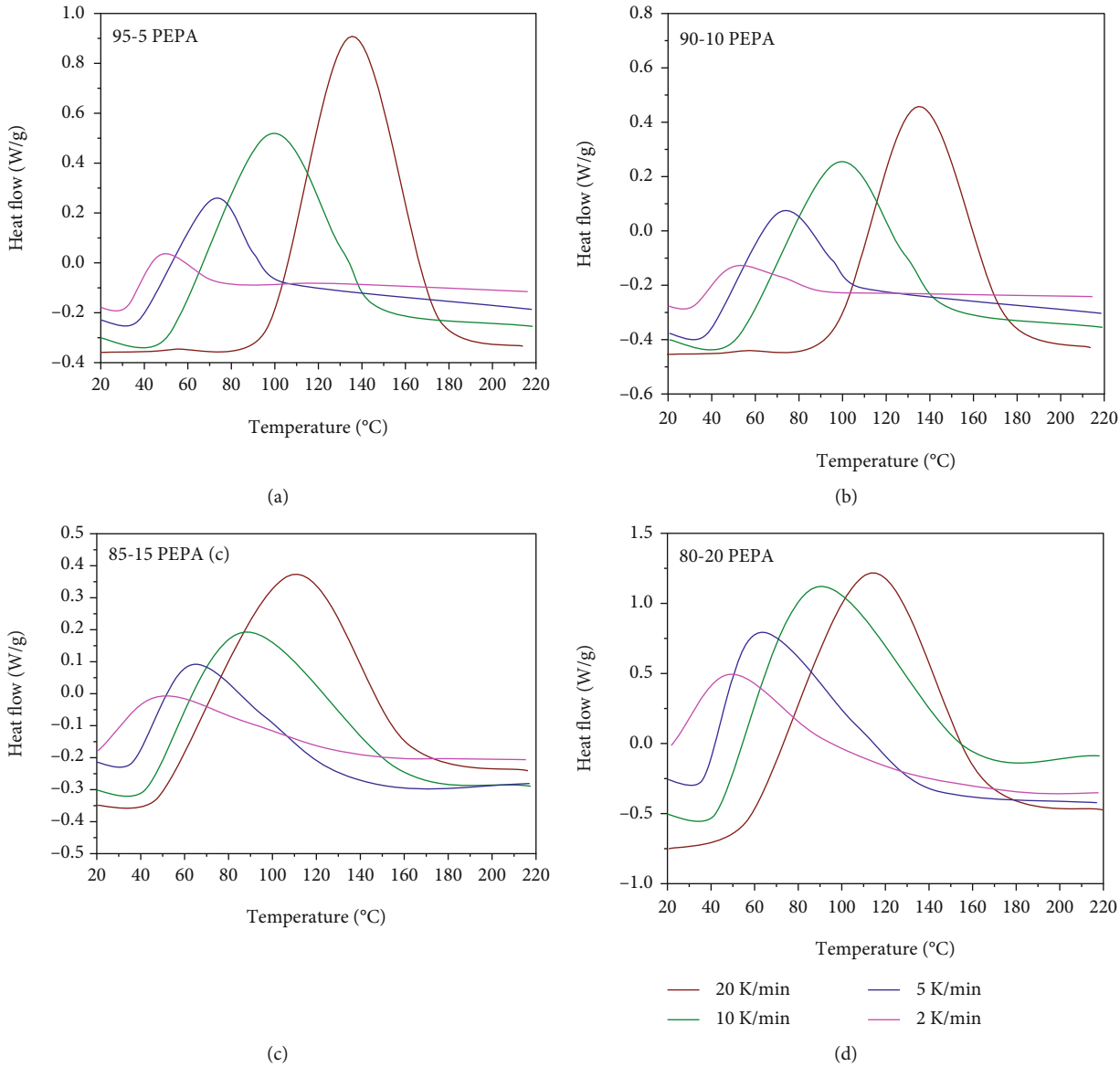

Figure 3: Differential scanning calorimetry curves of polyethylene polyamine: (a) 95-5; (b) 90-10; (c) 85-15; (d) 80-20.

above. The network is created by the reaction between oxirane rings and secondary amines.

We selected Flynn-Wall-Ozawa and Kissinger-Akahira-Sunose from various kinetic methods to analyze kinetic parameters. They give data on the link between activation energy and degree of curing (α) during the process. It is possible to obtain an activation energy value using either integral isoconversational approaches without deciding the reaction form. Both approaches' activation energy fit graphs are displayed in Figure 6, and their consequences are listed in Table 3 for convenience.

Ea is displayed in Figure 7 about the degree of cure (α). Even though the Flynn-Wall-Ozawa approach results in Ea values 3 to 6 kJ/mol greater than the Kissinger-Akahira-Sunose method, overall trends in Ea are similar. Polyethylene polyamine toughened compositions did not experience any significant activation energy decrease upon conversion, as seen by these dependencies. On the other hand, these graphs allow us to identify three stages of reaction. Because the final curing condition occurs at a higher temperature in a nonisothermal experiment, thermal energy overcomes the diffusion limitation, and only chemical parameters influence reaction activation energy. Non- or pure catalytic interaction of hydroxyl groups with isocyanate groups in this composition can be attributed to the rise in activation energy at the early stage. However, aromatic amines' catalytic activity is significantly lower than their aliphatic counterpart, making this process more challenging to catalyze. Amines and oxirane rings react during the second stage of curing. Curing is self-catalytic, which lowers the activation energy of the process. In this tendency, polyethylene polyamine's high activity as a hardener and catalyst is leveled.

Analysis of epoxy resin curing kinetics plays a critical role in establishing precise formulations and improving curing procedures (Table 4). To determine the most important

Table 2: Differential scanning calorimetry curing parameters of polyethylene polyamine and systems.

Specimen	β	T_{onset} (°C)	T_{peak} (°C)	T_{endset} (°C)
95-5 polyethylene polyamine	2	35.24	73.14	110.62
	5	46.12	88.62	142.12
	10	54.36	105.42	154.45
	20	67.11	124.32	189.63
90-10 polyethylene polyamine	2	35.62	72.84	113.62
	5	46.66	90.42	146.48
	10	57.82	106.62	168.32
	20	77.06	124.52	195.44
85-15 polyethylene polyamine	2	36.42	66.10	126.08
	5	48.13	87.24	149.81
	10	55.88	100.04	172.12
	20	64.14	116.62	184.62
80-20 polyethylene polyamine	2	32.22	60.62	112.42
	5	44.42	83.64	131.12
	10	55.24	94.12	165.88
	20	69.87	106.11	199.82

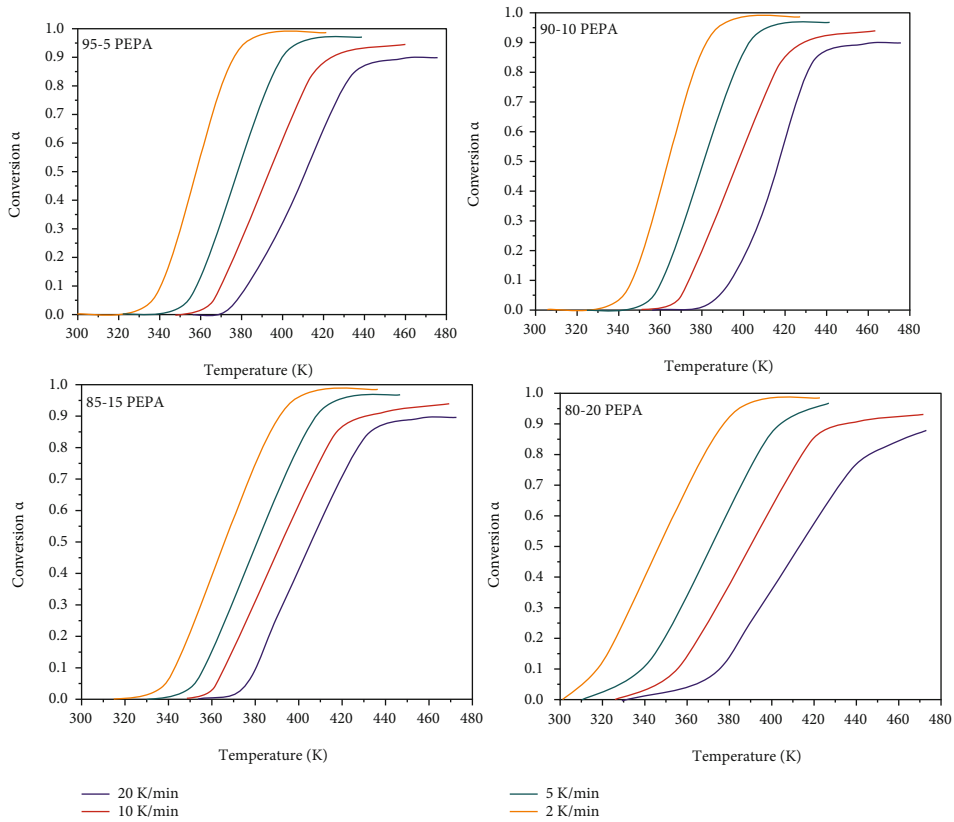

Figure 4: Polyethylene polyamine temperature vs. conversion curves at various heating rates: (a) 95-5; (b) 90-10; (c) 85-15; (d) 80-20.

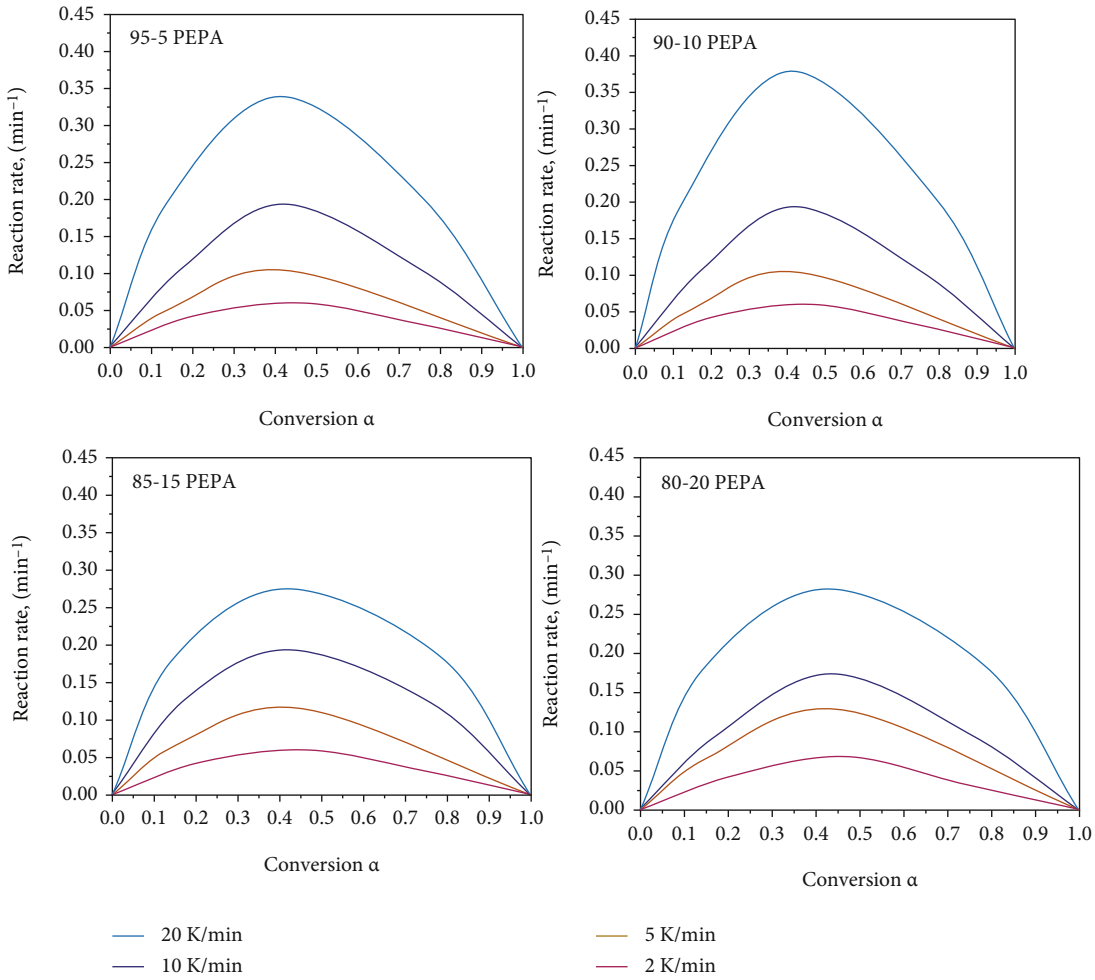

Figure 5: Nonisothermal reaction rate $d\alpha/dt$ as a function of cure degree α for the curing reaction at the indicated heating rates.

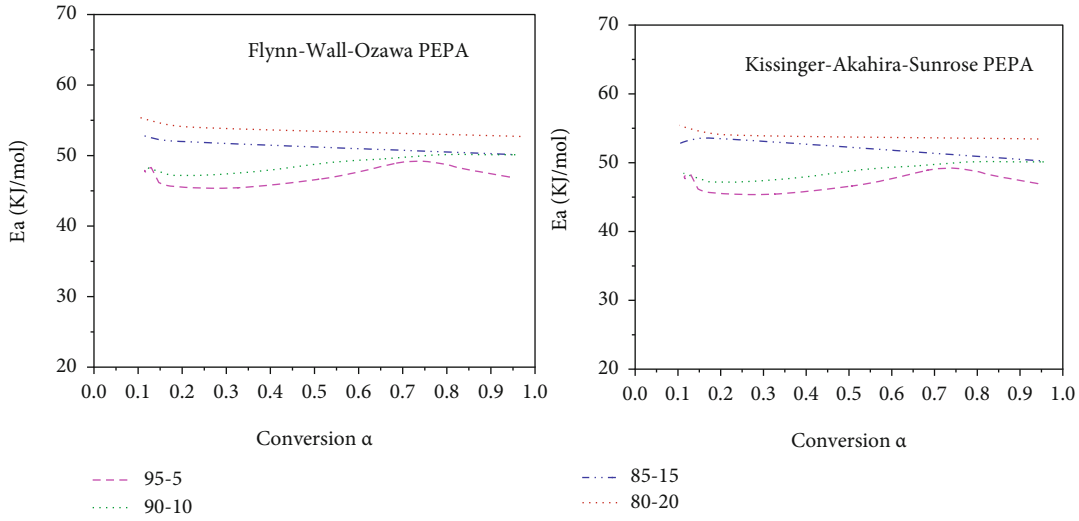

Figure 6: Flynn-Wall-Ozawa and Kissinger-Akahira-Sunose techniques were used to determine the activation energy vs. conversion degree of the PU/epoxy systems studied.

Table 3: Overall activation energies for all compositions.

Sample	β (k/min)	Ea (KAS)	Polyethylene polyamine Ea (FWO)	α_m	$\alpha^{-}{}_p$
95-5	20	37.6-42.5	42.8-46.4	0.18	0.47
	10			0.19	0.51
	5			0.21	0.52
	2			0.23	0.56
90-10	20	40.05-42.8	45.5-48.2	0.18	0.50
	10			0.19	0.51
	5			0.20	0.55
	2			0.21	0.54
85-15	20	42.8-48.1	45.7-51.1	0.16	0.51
	10			0.17	0.50
	5			0.18	0.50
	2			0.20	0.51
80-20	20	43.7-50.1	48.1-53.5	0.18	0.53
	10			0.19	0.52
	5			0.20	0.53
	2			0.19	0.53

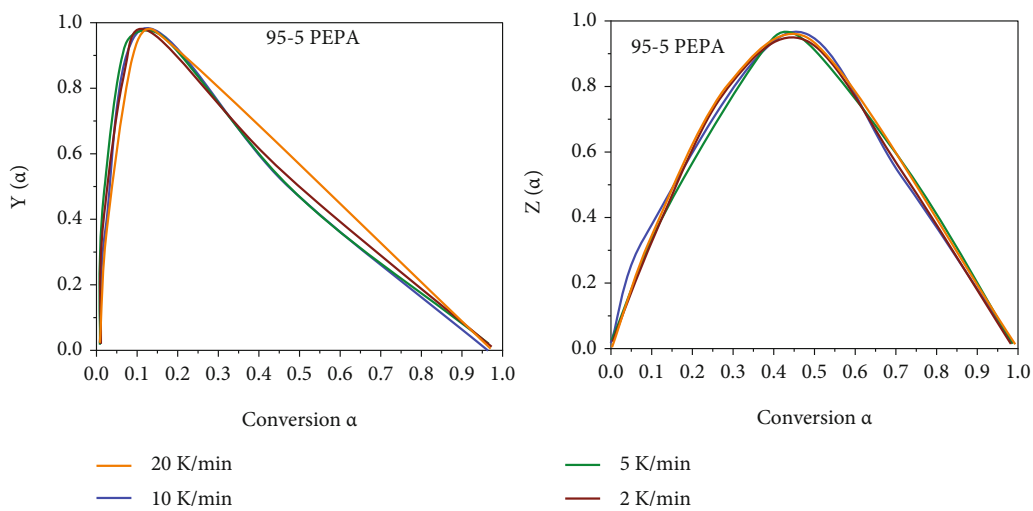

Figure 7: Functions of $y(\alpha)$ and $z(\alpha)$ vs. conversion degree.

curing kinetic parameters, we turned to [22]. $y(\alpha)$ and $z(\alpha)$ are two model functions used in this method to estimate kinetic parameters:

$$y(\alpha) = \frac{d\alpha}{dt} \cdot e^{x}, \tag{2}$$

$$z(\alpha) = \pi(x) \cdot \frac{d\alpha}{dt} \cdot \frac{\beta}{T}, \tag{3}$$

$$\pi(x) = \frac{x^3 + 16x^2 + 86x + 98}{x^4 + 18x^3 + 124x^2 + 246x + 124}, \tag{4}$$

where $x = E_u/RT, \pi(x)$, is the integral temperature, accurately evaluated by Senum-Yang Equation (3). We utilized the activation energy acquired by the KAS technique to compute the $y(\alpha)$ and $z(\alpha)$ functions since it was more appropriate. According to the graphs in Figure 6, the conversion of $y(\alpha)$ and $z(\alpha)$ parameters is depicted. It lets us regulate constraints α_m and α_p^{∞} as extreme spots in Table 3.

As shown, for all experimental settings, the values of αm and $\alpha\infty p$ did not rely on the heating rate suggesting the exact curing mechanism, according to Malek's methodology ($\alpha\infty p \neq 0.632$ and $0 < \alpha m < \alpha\infty p$); these findings support the autocatalytic character of cure. To calculate kinetic parameters, we can utilize Equation (2). Table 3 lists these values. Increased use of active hardener (polyethylene

Table 4: Kinetic parameters.

Sample	β (°C/min)	PEPA		
		ln A	m	n
95-5	20	7.815	0.241	1.206
	10	7.902	0.254	1.212
	5	8.012	0.302	2.232
	2	8.116	0.273	1.196
	Average	7.9612	0.265	1.461
Reaction rate constant			$k(T) = 0.28 \cdot 10^4\, e^{(-37751/RT)}$	
90-10	20	8.562	0.248	1.282
	10	8.491	0.271	1.304
	5	8.423	0.294	1.332
	2	8.451	0.315	1.328
	Average	8.481	0.282	1.311
Reaction rate constant			$k(T) = 0.51 \cdot 10^4\, e^{(-48262/RT)}$	
85-15	20	9.416	0.212	1.270
	10	9.318	0.206	1.178
	5	9.381	0.232	1.190
	2	9.452	0.278	1.240
	Average	9.392	0.232	1.219
Reaction rate constant			$k(T) = 1.43 \cdot 10^4\, e^{(-52561/RT)}$	
80-20	20	10.118	0.286	1.494
	10	10.168	0.266	2.280
	5	10.352	0.248	1.116
	2	10.389	0.250	1.206
	Average	10.256	0.262	1.524
Reaction rate constant			$k(T) = 3.26 \cdot 10^4\, e^{(-47463/RT)}$	

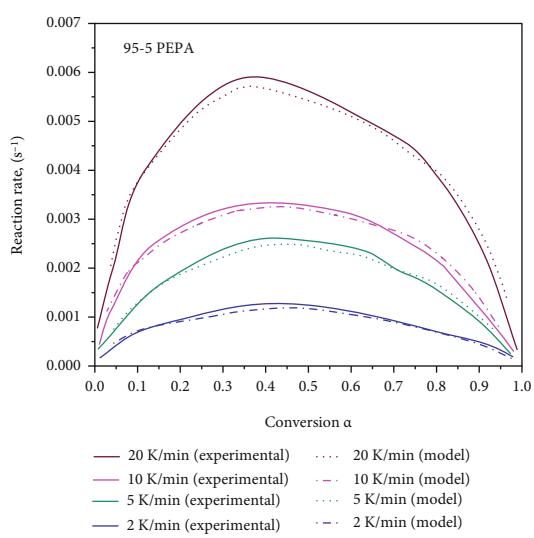

Figure 8: The autocatalytic model is compared to the experimental data.

Table 5: Mechanical properties of polyethylene polyamine.

Specimen	TS (MPa)	ε (%)	CS (MPa)	Hardness
100-0 polyethylene polyamine	51.6	1.1	112	84
95-5 polyethylene polyamine	46.8	1.3	107	81
90-10 polyethylene polyamine	40.2	1.2	99	79
85-15 polyethylene polyamine	36.7	1.6	96	78
80-20 polyethylene polyamine	32.8	1.8	92	76

polyamine) reduces n values, as can be shown. The autocatalytic curing of both hardeners occurs at almost the exact grade, as evidenced by the identical values of m. According to the autocatalytic model, Figure 8 compares the experimental data and the graph depicted using the model parameters calculated above. The experimental results and the cure kinetic model are in good accord in dynamic scans.

3.2. Epoxy Resins with Cured Mechanical Properties. Tensile test results for curing formulations are summarised in Table 5. The structural changes in composites have a substantial influence on their mechanical characteristics. Because the microphase zones have the elasticity of polypropylene, they weaken the overall tensile strength of composites. As the percentage of polyurethane in the composition and the elongation increase, the tensile strength decreases. Because of the lengthy curing process, composites with a more uniform structure are formed, which improves their mechanical properties.

4. Conclusion

This study has examined the curing dynamics and mechanical characteristics of bisphenol A diglycidyl ether-based epoxy resin with the polymer of aliphatic polyamine or a combination of less molecular aromatic amines. Networks are created by amine hardeners that respond with epoxy to form linear oligomers, followed by secondary amines that react with epoxy oxirane rings obtained in the second phase. A three-stage cure procedure is employed: Flynn-Wall-Ozawa and Kissinger-Akahira-Sunose isoconversional methods are used to evaluate the activation energy as a function of cure degree. Ea and α were shown to be correlated using these approaches, indicating that the curing systems under investigation had autocatalytic effects. Interestingly, among all materials tested, combinations of low molecular weight aromatically substituted alkylamines showed the most significant increase in strength and lengthening when the compositions were dried. Essentially, this means that composites with a more regular structure are better able to withstand mechanical stress because of a more gradual curing process.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Mechanical Properties of Arecanut and GFR Hybrid Polypropylene Composites

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The mechanical characteristics of hybrid polypropylene composites may be enhanced by adjusting the fibre loading and ratio, according to this study. The hot press technique was utilised to generate a variety of composites with four different amounts of fibre loading. In addition, the fibre ratio in composites with a 20-weight-percent fibre loading was changed. The composites were characterised using Fourier transform infrared analysis as well as tensile, flexural, and hardness tests. In the composites that have been created, Fourier transform infrared examination showed that hemicelluloses, lignins, and moisture were present, all of which have the potential to reduce tensile strength. Fibre loading resulted in a decrease in tensile strength but an increase in Young's modulus. With increasing fibre loading, flexural modulus and hardness rose, whereas flexural strength declined. The best mechanical qualities were found in a composite made primarily of arecanut and glass fibres, with a weight ratio of 1 : 3.

1. Introduction

Design freedom is provided by hybrid fibre–polymer systems, which allow for the tailoring of composites and the attainment of qualities not possible in binary systems comprising the same fibre/filler in matrix [1]. In few cases, benefits of one fibre can outweigh the drawbacks of another. As a result, proper material design could bring about a performance-to-cost equilibrium [2, 3]. Automotive industry is the primary consumer of natural fibres because of their functional characteristics. Mirror frames, doors, windows, and other interior sections can all be made from composites, as can truck cabs, panels, shelves, and other trim components [4–6]. Composites are also popular in the production of brake shoes. Palm tree species (*Areca catechu*) bear the arecanut fruit (also known as the arecanut) and are found throughout Asia [7]. Fibres made from arecanuts are inexpensive. The fundamental issue with natural fibre composites is their incompatibility with polymer matrixes due to the hydrophobic nature of natural fibres [8–10].

Polymeric matrix composites commonly use glass fibres as reinforcement. Many applications benefit from its low cost, strong tensile strength, resistance to chemicals, and insulating properties [11, 12]. Among the most commonly

used types of fibres in fibre reinforced plastics, E and S glass are the most prevalent. E-glass fibres are the most commonly utilised reinforcing glass fibres in the fibre-reinforced plastic industry because of their low cost [13, 14]. It is possible to get the desired properties by combining fibres in the right way and orienting them in the right direction. Fibre composites are stiffer than aluminium and have a specific gravity one-fourth that of steel, but they have the same functional properties as steel [15]. In the nautical, automotive, and piping industries, glass fibre-reinforced composites (GFRCs) have become increasingly popular because of specific strength and stiffness, along with their resilience to corrosion and impact damage [16]. Fillers, on the other hand, enhanced the properties of composites while also lowering the overall cost of the final product. We see polymers in practically every facet of modern life, from high-tech devices like artificial hip and knee joints to single-use plastic utensils for food [17].

Linear hydrocarbon polymers such as polypropylene are widely utilised in textiles, lab equipment, and automobile parts. Polypropylene is available in densities varying from 0.91 to 0.97 g/cc and is completely linear [18]. Polypropylene composites offer good flowability, mechanical properties, weatherability, and chemical resistance and are cost-effective when compared to other materials. These composites are widely employed as a key raw material, particularly in vehicle parts. Natural fibres that have been hybridized with synthetic fibres have been the subject of extensive study. However, no studies have been done on the use of arecanut and glass fibres in a polypropylene matrix. It is so hoped that this paper may provide some light on the hybridization of arecanut and glass fibres with polypropylene [19, 20]. Because of its inexpensive price, polypropylene was selected as the matrix material. Our approach of making eco-friendly hybrid composites out of natural fibres is described in this publication [4, 21, 22]. The paper focuses on the interaction of arecanut fibres with glass and polypropylene in this application.

Hybrid fibre-based polymer composites are created all over the world to give designers greater creative freedom when creating composites and to provide features that cannot be achieved in binary systems using only a kind of fibre or filler discrete in the matrix [23, 24]. They provide balanced strength and stiffness, increased bending and mechanical characteristics, improved fatigue and impact resistance, improved fracture toughness and crack arresting qualities, and decreased weight and cost. Polymer-based composites have been used to tackle technological difficulties since the 1960s [22]. Fibre composites that combine two or more types of fibre can fill in the gaps left by the omissions in the original design. As a result, good material design allowed for a trade-off between performance and cost. To improve the composite's mechanical strength and other qualities, stronger synthetic or natural fibres can be hybridized with natural fibres [25]. The automotive sector prefers natural fibres because of their beneficial properties. Because of its biodegradable nature, natural fibre-reinforced composites are both low-cost and environmentally friendly. As an additional benefit, lignocellulose fibres are nonabrasive, light in weight, and easy to get. They also take less energy to process, decrease the density of finished products, and absorb carbon dioxide at the time of their growth. For composites, lignocellulose fibres can be blended with either thermosetting or thermoplastic polymers. However, thermosetting polymers show the composite to be extremely brittle, making it impossible to repair. Natural fibres, despite their amazing properties, have gained popularity due to their little impact on the environment [4]. This palm tree, known as the *Areca catechu*, produces the arecanut fruit, which is widely available and thrives throughout Asia [26]. Due to deficiency of compatibility between natural fibres and the hydrophobic qualities of polymer matrix, the fundamental impediment to using natural fibre composites is lower fibre–matrix interfacial bond.

Figure 1: Universal testing machine setup.

On the other hand, polymeric matrix composites are commonly reinforced with glass fibres. Because of their inexpensive price, strong tensile strength, good chemical resistance, and excellent insulation, these materials are often preferred over others [27]. Fibre-reinforced plastics commonly use S-glass and E-glass fibres. Commercially accessible reinforcing glass fibres are more expensive than E-glass fibres. These composites have been tested for their mechanical properties. Composites bonded with polyester and oil palm fibre/glass were made for research in another work [28]. The researchers also looked at flax/glass-reinforced composites, jute/glass-reinforced composites, and basalt/glass-reinforced composites. There are a lot of studies being done that use a combination of glass and a natural fibre.

This polymer is utilised in textiles, laboratory equipment, food packaging, and automobile components because of its low cost [29]. Polypropylene's density ranges from 0.91 g/cc to 0.97 g/cc depending on the materials' availability. Natural fibres that have been hybridized with synthetic fibres have previously been the subject of extensive study. It is, however, the first time that arecanut and glass fibres have been used in conjunction with a polypropylene matrix. Arecanut's hydrophilic characteristic causes moisture absorption and, as a result, product deformation when used as a

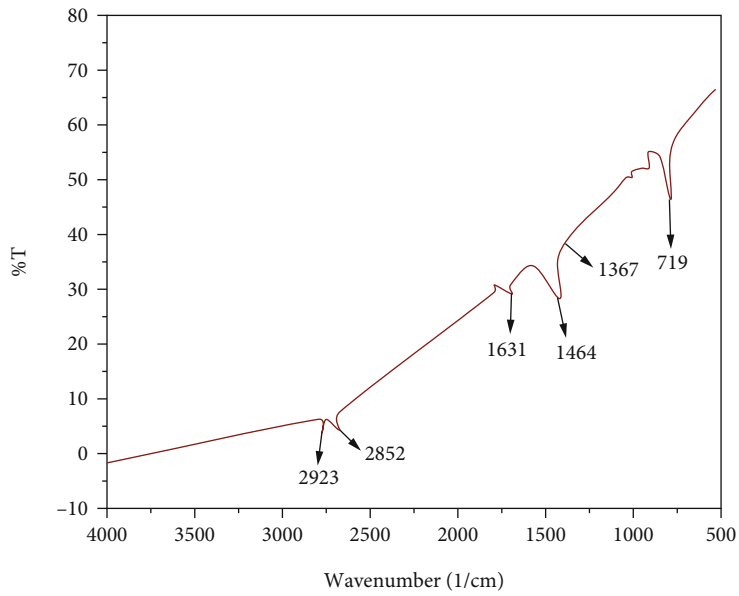

Figure 2: Fourier transform infrared spectrum of polypropylene.

fibre material. Fibre-matrix adhesion is critical to the strength of produced composites [30–32]. Fibre-polymer matrix interface bonding can be improved by modifying the fibre surface with alkaline treatment such as NaOH. NaOH solution was added to the arecanut fibres in order to improve their adherence. A major goal of this study is to create a composite containing raw and alkali-treated arecanut fibre, glass fibre, and polypropylene, as well as other materials [10]. Alkali treatment and fibre ratio have been shown to influence the mechanical and morphological properties of produced composites.

2. Methods and Materials

2.1. Materials. Polypropylene, arecanut, and glass fibre were all used in this experiment. The melting point of LDPE granular polypropylene was 140°C, and the material was white in colour. It was in granular form. The arecanut fibres were released by soaking it in water at room temperature for ten days. After that, nut was cracked open and the fibres of the arecanut extracted by hand.

2.2. Manufacturing of Composites. These hybrid composites are made using hot press process with several proportions of arecanut and glass fibre. The aluminium die has a 150 × 150 × 5 mm size. When the maximum load and temperature were both 35 kN, the hydraulic machine was used. The percentage of arecanut and glass fibres was altered from 5 to 20 wt percent, with a 1 : 1 ratio. Fibres with a diameter ranging from 3 to 5 mm were employed. A balance was used to determine the amount of fibre and polypropylene needed. The die was filled with the premixed mixture. The fibre–matrix mixture was pressed into the die with 30 kN of pressure. To begin with, the temperature was increased to 140°C and kept for around 18–20 minutes before being increased to 160°C. Depending on the thickness requirement, this is true. Cooling the die to room temperature was the next step. By relieving the pressure, the composites were removed from the die. This method was used to make all of the composites.

A spectrophotometer was used to record the FTIR spectra of arecanut–GFR hybrid composites in this study. To obtain the first powdered samples, a knife was used to scratch the composite. At a mortar pestle, the samples were mixed with potassium bromide (KBr) in a 1 : 1 ratio. Using a mechanical presser with an 8-ton pressure rating, the mixture was compressed into a pellet and deposited on a sample holder for spectroscopic analysis.

2.3. Mechanical Testing. Tests for tensile, flexural, and hardness were conducted. There were five samples analyzed and average values were presented for each. A head speed of 4 mm/min was applied on a UTM machine for the tensile test in accord with standard of ASTM D 638-01, and the setup is shown in Figure 1. The same testing machine was used to conduct static flexural tests in accordance with ASTM D 790. A durometer hardness tester set on Shore (A) scale was used to gauge the composite's hardness.

3. Results and Discussion

Figure 2 depicts the polypropylene FTIR spectrum. The most prevalent applications include identifying unknown materials and confirming manufacturing materials, as well as performing qualitative and quantitative analyses of organic molecules and determining the chemical structure. CH_2 (methylene) symmetrical strong stretch, methylene asymmetric stretch, bending deformation, medium wagging deformation, and the occurrence of water vapour in the air are all seen in the spectrum at 2923 cm. It can be seen in Figure 3 that the absorption highest point at 3477 cm^{-1} corresponds to a –OH group, while other peaks related to the

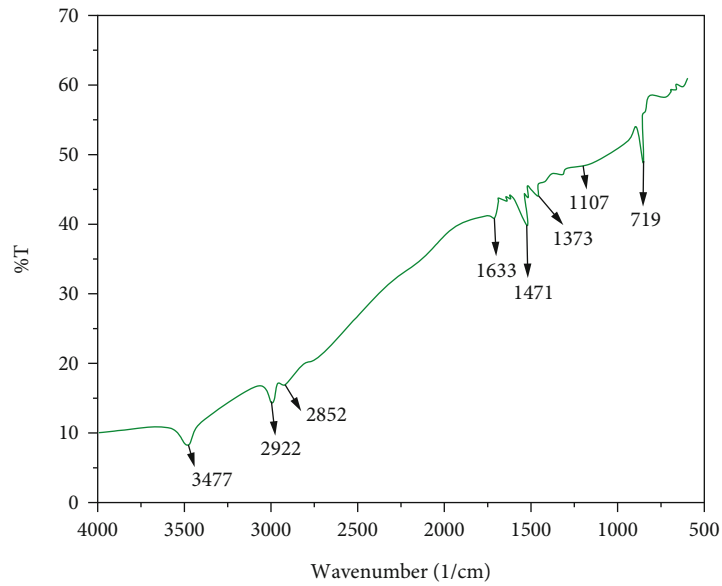

Figure 3: Fourier transform infrared spectrum of arecanut glass (1 : 3) 20 wt% fibre-reinforced composite.

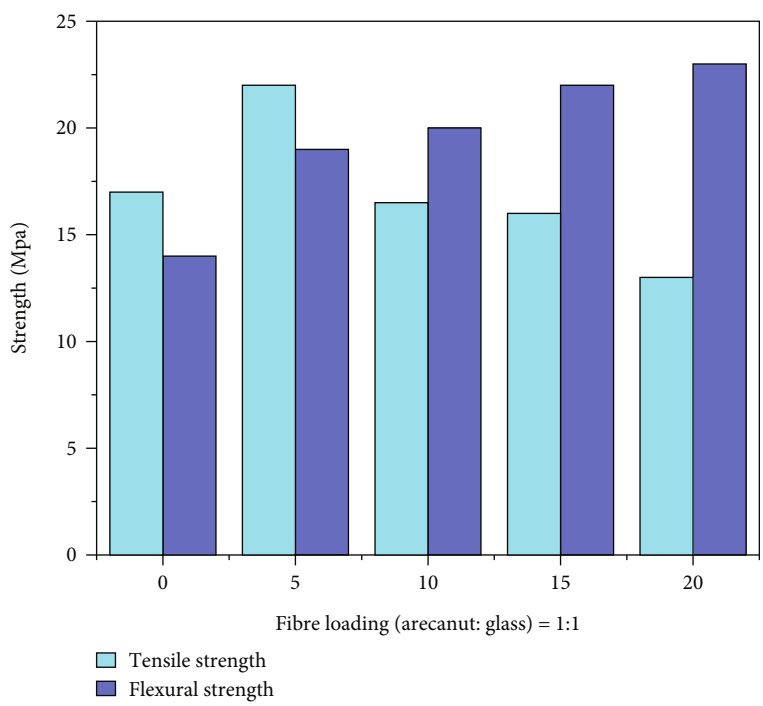

Figure 4: Variations in tensile and flexural strength with diverse fibre loadings.

aromatic C=C in-plane alkenes and C-H bond of the various components of the composite are depicted.

3.1. Tensile and Flexural Strength. Measurements were made with 5, 10, 15, and 20% fibre content. Tensile strength decreased with increasing fibre loading. Fibre loading was initially increased to 5%, but as fibre loading grew further, the interfacial bonding between the fibre and its matrices became less stable and hence lowered its mechanical properties over time and it is shown in Figure 4.

Composites with a fibre content of 5, 10, 15, and 20 wt percent had their flexural strength evaluated as well. Fibre loading enhanced the flexural strength of the material. It is possible to overcome weak fibre–matrix adhesion due to proper alignment of polypropylene chains with the fibre. Flexural strength is strengthened when fibre loading increases because of the increased likelihood of robust fibre–matrix adhesion, and it is shown in Figure 5.

In this case, Young's modulus rose as the fibre loading raises. Separate microspaces are formed when the interfacial

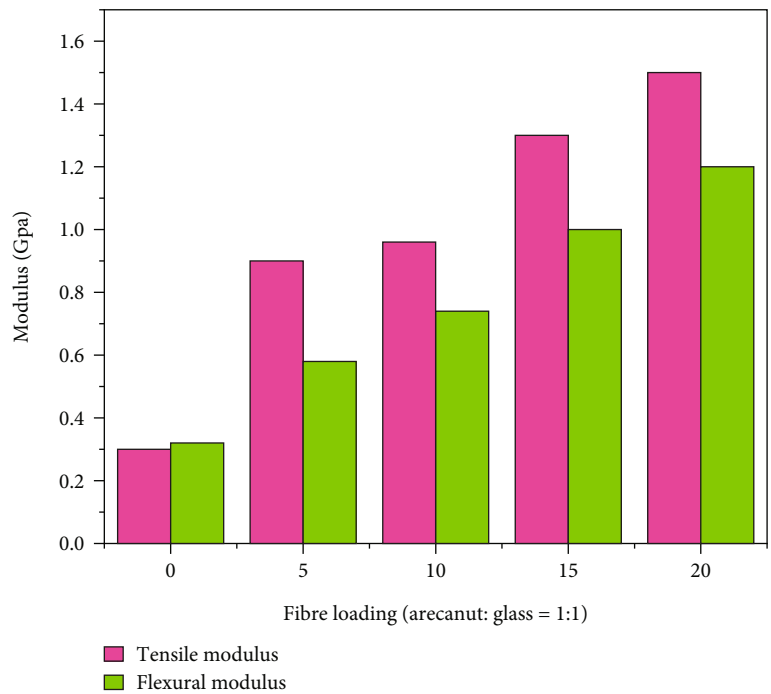

Figure 5: Variations in tensile and flexural modulus with unlike fibre loadings.

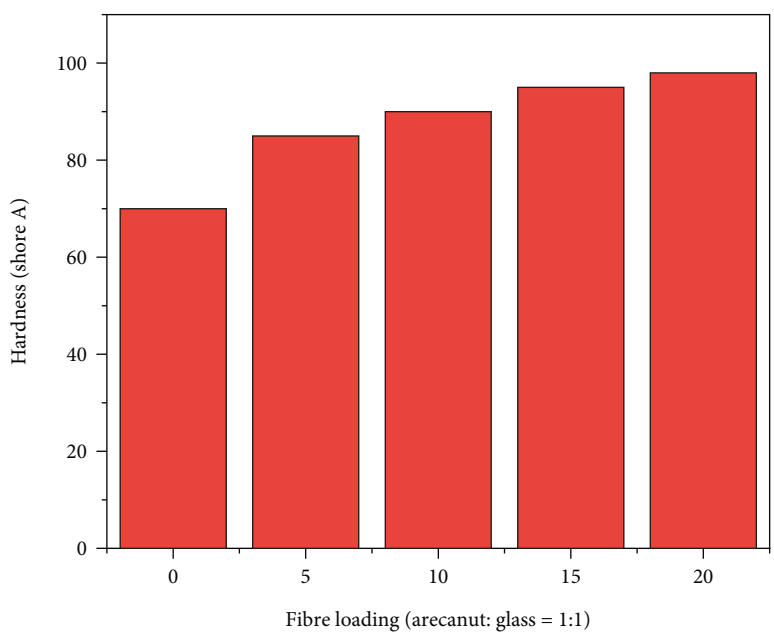

Figure 6: Different fibre loadings cause a change in hardness (Shore A).

connection among fibre and matrix becomes poor or weak. Increasing the fibre load, the obstruction to stress propagation becomes more severe, leading to an increase in stiffness. Adding fibre to the polymer matrix also reduces the mobility of the matrix, which in turn increases stiffness. High modulus materials include arecanut and glass. Increased fibre concentrations require a greater amount of stress in order to get the same deformation. Flexural modulus increased as fibre loading was applied, according to the findings. A possible explanation for these results is that the soft PE matrix was strengthened by the addition of hard glass fibres. As a result, the flexural modulus of the soft polypropylene matrix was raised by including high modulus fibres.

3.2. Hardness Analysis. When the matrix is more flexible, it has a lesser hardness, like raw polypropylene. The degree to which the fibres are evenly dispersed throughout the matrix affects the composite's hardness. According to this

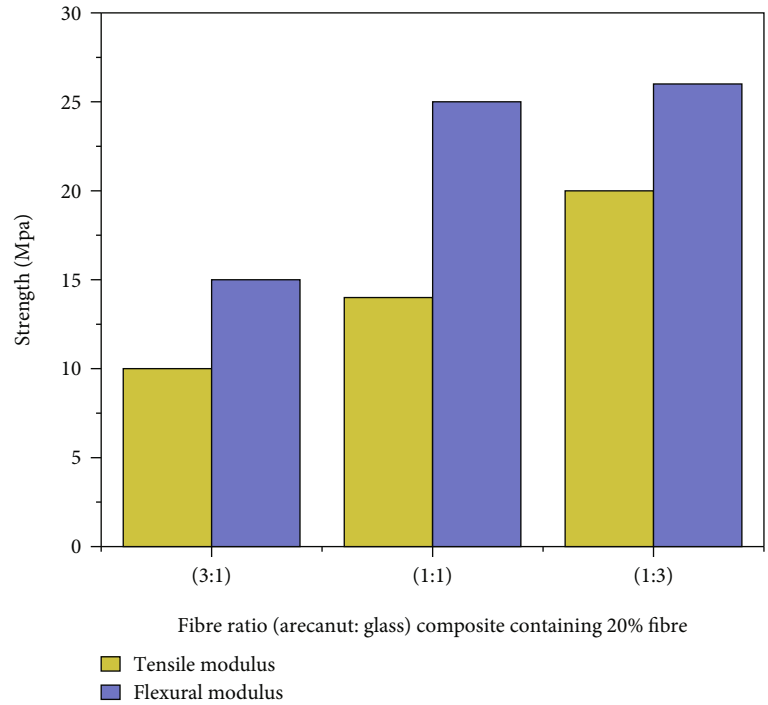

Figure 7: Variation in tensile and flexural strength for 20 wt% fibre loading at various fibre ratios.

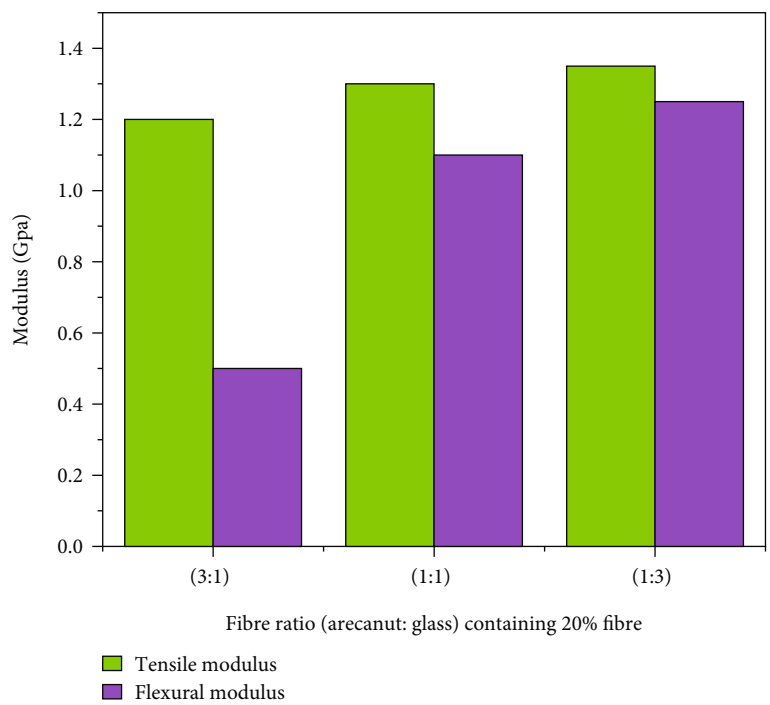

Figure 8: Tensile and flexural modulus variations with a 20 percent fibre load for varied fibre ratios.

study, raw polypropylene's hardness rises to around 90 when the fibre level exceeds 15% by weight. The hardness of the material was improved by reducing the number of spaces among the matrix and fibre. Polypropylene becomes more difficult to work with when more fibres are included into the resin. Figure 6 depicts the change in hardness as a function of fibre loading.

3.3. Effect of Fibre Ratio. The orientation and architecture of fibres have a big impact on the impregnation surrounding them. A larger fibre volume fraction usually means the composite has superior mechanical characteristics. There is a noticeable difference in performance between arecanut and glass fibre-reinforced composites, as demonstrated in Figures 7–9. With increasing glass fibre loading, the tensile

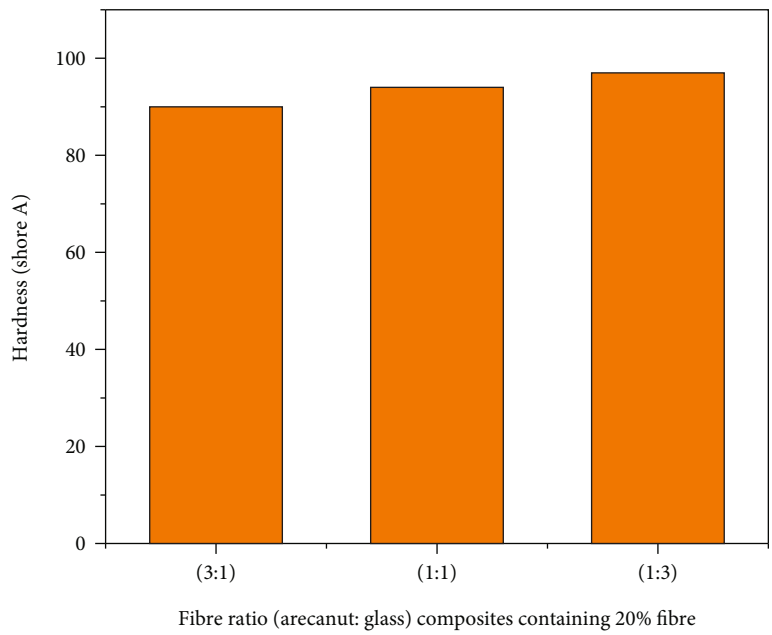

Figure 9: Variation in hardness (Shore A) for 20 wt percent fibre loading at various fibre ratios.

and flexural strengths also rose. Tensile strength of a fibre is determined by its chemical composition and internal structure. A 1 : 3 ratio of arecanut to high-strength glass fibres (2.0 GPa) improved tensile strength compared to arecanut (166.03 MPa), as illustrated in Figure 7. Bending and shearing were the causes of failure in a three-point flexure test. When glass fibres were incorporated into the hybrid composites, they boosted the composites' flexural strength due to the greater resistance to shearing.

There can be shown in Figure 8 that with increasing glass fibre content, the tensile and flexural modulus rose. As a result, the composite's tensile and flexural modulus is increased. Because glass fibres are stiffer than arecanuts, a higher percentage of glass fibres in the composite raises the modulus. In order to improve flexural modulus, the glass fibre ratio was increased from one to three and it is seen in Figure 8. Figure 9 indicates that the hardness increased from 90.23 Shore A to 96.7 Shore A by increasing glass fibre ratio from 1 to 3.

Fibre aggregation is seen on the fracture surface of the composites comprising 20% arecanut and glass fibres with a 1 : 1 ratio. Tensile strength decreased because of insufficient interfacial bond among the fibre and polymer matrix. Composite with a 20 wt% fibre content and a 1 : 3 arecanut/glass fibre ratio demonstrated strong fibre dispersion and bonding properties. This composite had a higher tensile strength as at last. However, the tensile strength of the composite was lowered due to deboning and agglomeration of the arecanut and glass fibres in a 3 : 1 ratio. As a result, this increased interfacial area was undesirable.

4. Conclusions

According to the results of this investigation, polypropylene composites can be successfully used with arecanut and glass fibre as reinforcing fibres. The following outcomes have been taken from the experiments:

(i) The mechanical characteristics of the composite comprising 20% fibres at a ratio of 1 : 3 in arecanut and glass were the best

(ii) The interfacial fibre–polypropylene interaction in the 1 : 3 ratio arecanut–glass fibre composite was excellent

(iii) FTIR spectroscopy indicated the presence of hemicelluloses, lignin, and –OH groups in the arecanut; there was evidence of weak interfacial bonding in the composites

(iv) Glass fibre ratios of 1 to 3 result in maximum flexural strength of 24.13 MPa and maximum flexural modulus of 1.17 GPa

(v) The produced composites' tensile strength reduced, while their Young's modulus rose, as the fibre loading rose. From this, 19.36 MPa maximum tensile strength and 1.23 GPa maximum Young's modulus are found

(vi) Compared to polypropylene, the composite has a maximum hardness of 96.7 (Shore A)

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Mechanical Properties of Ramie/Hemp Hybrid Composites Influenced by Stacking Arrangement and NaOH Treatment

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This research is aimed at seeing how different stacking sequences and chemical treatments impact the mechanical characteristics of ramie–hemp composites. Hand-lay-up procedures were used to create a blend of woven ramie and hemp fibers. The woven ramie was treated with a diluted 6% sodium hydroxide (NaOH) solution to compare the mechanical properties of preserved and unpreserved ramie hybrid composites. According to the findings, the tensile properties of hybrid composites are better in three-layer composites than in four-layer composites. Hemp-based hybrid composites outperform other hybrid composites in terms of mechanical properties. Hybrid composites that have been treated have better tensile and flexural properties than hybrid composites that have not been treated. The sample H/R/H/R was found to have the best impact characteristics. This research is part of a more extensive investigation of hybrid composite's application in high-velocity impact applications.

1. Introduction

Natural fibers of diverse dimensions and properties, produced from plants, animals, and minerals, have been widely employed to suit textile demands for a long time. [1]. Like cotton, plant fibers have been beneficial for thousands of years, gaining the nickname "white gold." Two plant-based materials are now being utilized in combination with natural fibers [2, 3]. Polymer composites outperform traditional materials in terms of engineering. Chemical resistance is higher in polymers than it is in metals. Biodegradable and replenishable, natural fibers are a precious resource. Natural fibers provide a number of advantages over synthetic fibers, including the fact that they are nonabrasive, have a low density, have good acoustic properties, are less expensive, are more readily available, and can be recycled more easily [4]. Composites can benefit from the use of ramie (Hibiscus cannabinus L.), which can replace synthetic fibers and other traditional materials. Among the many benefits of using ramie over synthetic materials are the fact that it is cheaper, less dense, more flexible, nonabrasive, toxic-free, reusable, and biodegradable [5–7]. Natural fibers, while their advantages, have some limitations in the industry. The low heat stability, high moisture absorption rate, and poor adhesion to synthetic alternatives limit the utilization of natural fibers in industrial applications. Natural fibers have been chemically modified and hybridized with synthetic fibers in the majority of situations [8]. Natural and synthetic fibers can be

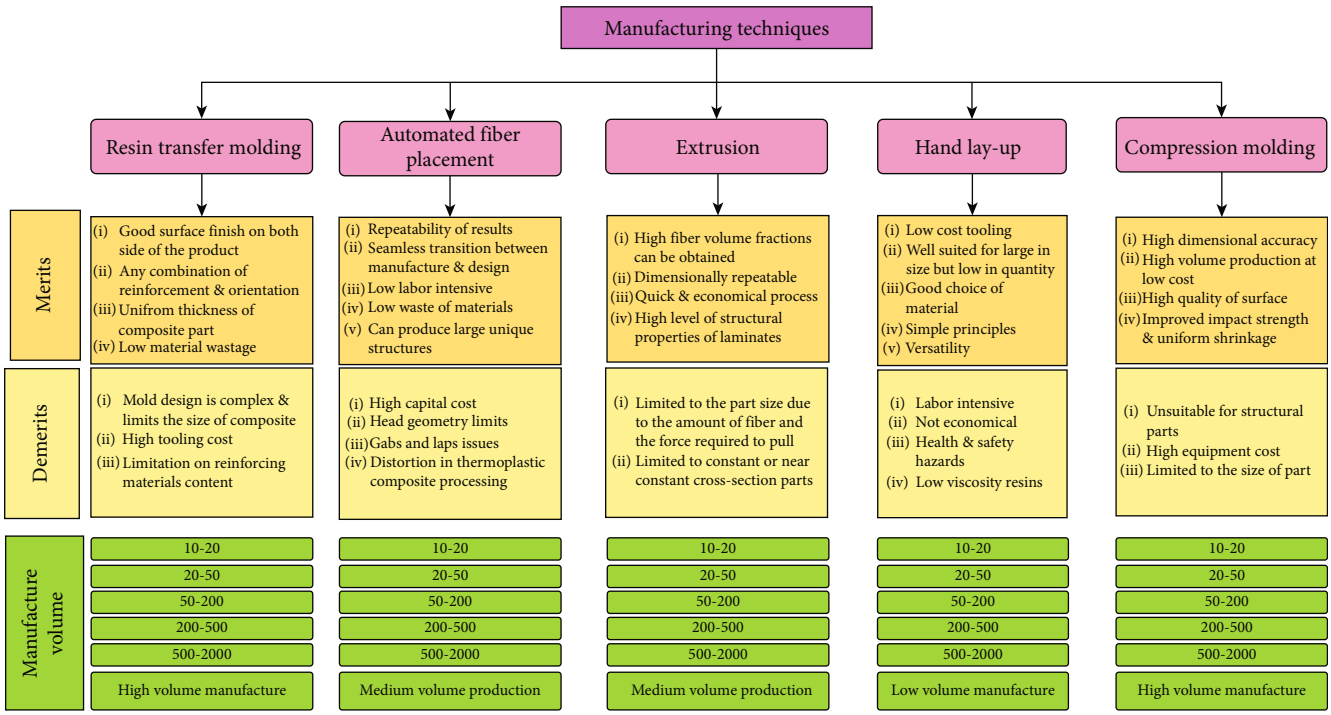

Figure 1: Manufacturing techniques of polymer composites.

Table 1: Properties of hemp fiber.

Properties	Hemp
Diameter of the fiber	13.00 (μ)
Density of fiber	1.48 (g/cm^3)
Tensile modulus	101.2 (GPa)
Breaking elongation	2.90(%)
Density of fabric	8.62(per cm)
Weight of the fabric	194.28(g/m^2)
Tensile strength	3.58 (GPa)
Thickness	0.41(mm)

Table 2: Properties of ramie.

Properties	Ramie (nonpreserved)	Ramie (preserved 6% NaOH)
Breaking load (N)	145.6	88.4
Fabric tensile strength (MPa)	10.2	4.12
Fabric elongation at break	16.12	41.5
Fabric thickness (mm)	3.06	4.06
Weight (g/m^2)	612.1	710.2

combined in the same matrix to form hybrid composites, which are perfect, superior, and cost-effective [9, 10]. Synthetic–natural fiber hybrid composite research focuses on decreasing the number of artificial fibers. Synthetic fibers collectively referred to as "aramid" are included in the Aramid family of materials [11]. Figure 1 reveals the manufacturing techniques of polymer composites.

Hemp materials are more resilient, permeable, and insulated than other fabrics. Secondly, it does not lose their form when stretched. Hemp is an ideal upholstery fabric because it can be pulled taut and stay firm for the duration of its life. Hemp is by far the most popular fiber in this family. As a result, high-performance personal body armor, ballistic helmets, and a wide range of other ballistic uses have become commonplace. The use of synthetic aramid fibers in ballistic protection is usually under investigation [12–15]. Many natural synthetic fiber-based hybrid composites, such as those based on plant fibers such as pineapple or palm or ridge gourd or jute or sisal or carbon, have recently been identified. [16] studied the effects of hybridization on mechanical and physicochemical properties of oil palm EFB/glass hybrid reinforced polyester composites. According to the study of [17], hybrid composites were found to be superior to EFB/polyester composites in terms of quality. Chopped jute fiber mat hybridized with bagasse in novolac composites is studied by [18] using a unique stacking strategy. According to the researchers, epoxy novolac composites reinforced with jute–bagasse hybrid fibers could be used as high-performance applications. The mechanical characteristics of polyester composites reinforced with sisal fibers were enhanced using carbon fiber. When [19, 20] studied the mechanical properties of an interwoven jute/glass cloth, they created a hybrid composite. Ramie–aramid hybrid composites' mechanical characteristics have been published. Long ramie fibers and hemp were combined in an experiment.

Table 3: Characteristics and layering order of specimens.

Specimen	Composition	Weight percent	
		Ramie	Hemp
H/R/H	Hemp/ramie/hemp	43.51	61.5
R/H/R	Ramie/hemp/ramie	41.64	63.9
H/R/H/R	Hemp/ramie/hemp/ramie	49.21	62.8
Hemp	Hemp/epoxy	0	62.4
R/E	Ramie/epoxy	43.12	0
R/ET	Ramie/epoxy (treated)	44.1	0

Figure 2: Shows the schematic view of impact testing machine.

[21] examines the ability of coconut coir to withstand high-speed impact penetration by lowering the amount of synthetic fiber used in composites in their study of woven coir/hemp composites. The mechanical characteristics of hybrid composites are influenced by factors such as the layering sequence of fibers in the structure [22]. It was found that the layering sequence had an impact on the tensile and flexural performance of trilayer oil palm EFB/woven jute fiber-reinforced epoxy hybrid composites, according to [23, 24] in relation to glass hybridization and stacking sequence. The effect of NaOH treated hemp fiber fly ash mortar composites was studied for mechanical characterization [25]. Polymer breakdown is reduced by using UV stabilizers and colorants [26]. In addition to preventing polymer breakdown, colors and UV stabilizers improve how the polymer is perceived by the eye. Lubricants increase surface quality and boost throughput, while UV stabilizers and coupling agents link fibers and resin. Using chemical treatments, such as the alkaline-silane treatment, has been beneficial for ramie composites. According to research conducted by [27], the treated woven betel palm composites beat the untreated composite in flexural and impact performance. Polyethylene terephthalate (PET) is a thermoplastic resin that can be used to make synthetic fibers such as polyesters and nylons. To minimize water uptake, chemical surface treatments were applied to the Alfa (Stipatenacissima) fiber by [28, 29]. Oil palm EFB fibers undergo a chemical modification that changes their mechanical and thermal dynamic properties. Increased wettability and strong fiber/matrix interface bonding arise from the change in hydrophilicity, resulting in a substantially stiffer hybrid composite with a high storage modulus. Polypropylene composites made of jute–coir fibers reinforced with 5 percent NaOH showed an improvement in mechanical properties, according to [30]. Weaved composites have been shown to alter their properties and provide superior impact resistance than unidirectional composites [31–33]. It was found that the treated woven ramie composite was more durable and elastic than untreated woven ramie composites in terms of flexural strength and modulus. POM and PET composites reinforced with ramie fibers were studied by [34] to see how hybridization affected the mechanical properties. When compared to a woven ramie/POM composite, the tensile and impact strength of the interlaced POM/ramie/PET hybrid composite was much higher. Ramie–hemp hybrid laminate composites were explored in this work by varying the thickness of the ramie and hemp single ply layers [35–37]. The hybrid laminated composites were created by arranging plain woven ramie fabrics and hemp in diverse patterns. It was found that mechanical characteristics of woven ramie–hemp hybrid laminate composites depended on the stacking sequence and chemical treatment. A look at the composite's fracture behavior was also conducted [38–41].

2. Materials and Methods

2.1. Materials. Weaved ramie, hemp, and epoxy resin were used in this experiment. Hemp 129 is a higher-tenacity para-aramid fabric commonly utilized in ballistic applications. The hand loom weaving procedure used ramie yarns to create the woven ramie fiber (548 g/m). The thickness of woven ramie and hemp cloth is 2.3 mm and 0.3 mm. Table 1 lists specific features of hemp fibers. Table 2 lists the properties of ramie that were examined in this study.

2.2. Chemical Treatment of Ramie Fiber. The fabrics are initially cut into $200 \times 200\,\text{mm}^2$ squares for cutting purposes. The woven fabric and yarn were soaked in a 6% diluted NaOH solution for three hours before drying at room temperature for twenty-four hours to treat the ramie yarn. It was then rinsed with distilled water, dried for 24 hours in the open air, and then baked for another 24 hours at 60 degrees in an oven.

2.3. Production of Composite Materials. Composite laminates were made in a mould using a hand lay-up procedure and then subjected to a static load compression test (20×20cm). Composite laminates were divided into three categories. The first two varieties are made up of three layers

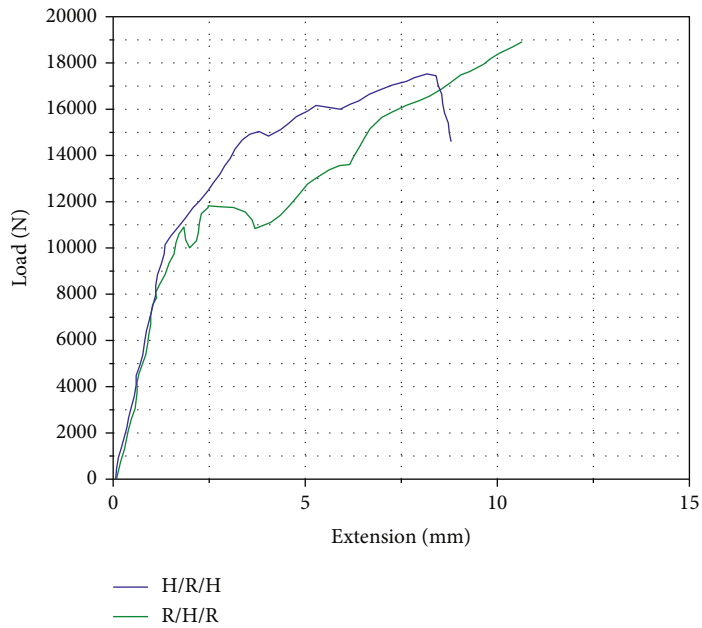

Figure 3: Load–extension curve for hybrid composites.

of two and four plies of ramie and hemp, respectively, in H/R/H and R/H/R layering sequences.

The second variety is made up of four layers of two and four plies of ramie and hemp, respectively, in H/R/H/R layering sequences. To evaluate hybrid composites with pure specimens, ramie/epoxy and hemp/epoxy were made. Ramie and hemp fabrics were laid up by hand using an epoxy matrix that was made by stirring epoxy resin and amine hardener in 2/1 ratio. Mold release agent was sprayed on the mould to keep the composites from adhering to it after curing and to keep the sample's surface smooth and even. At room temperature, we let the composites a 24-hour cure time before applying compression pressure to the mold's top. For two hours at 70 degrees Celsius, the specimens were postcured after they were removed from the mould. The matrix-to-fiber ratio in each hybrid composite was kept at around 70 : 30. Table 3 lists the properties and stacking sequences of hybrid composites.

2.4. Tensile Test. This hybrid laminated composite was tested using a tensile test to examine its stress–strain behavior. Plates having a thickness of 250 × 25 mm were used to test each composite in line with ASTM D3039-14. They were precisely cut using a wheel saw and finished in accordance with specifications. A 5 mm/min rate of normal head displacement was used. To get the average tensile strength and modulus values, five samples were taken from each sample and averaged.

2.5. Flexural Test. The flexural test was carried out using three-point loads in accordance with ASTM D790-10. A circular saw was used to cut rectangular samples measuring 100 × 20 mm. The crosshead was moved at a pace of 2.2 mm/minute for the studies. In order to get an accurate reading, five samples are analyzed at room temperature for each sample. In order to determine hybrid composites' flexural strength, we used the following equation:

$$\sigma_f = \frac{3PL}{2bd^2}. \quad (1)$$

$$E = \frac{L^2 m}{4bd^2}. \quad (2)$$

2.6. Impact Test. The ASTM: D256-10 is used to create and evaluate the impact test samples. Five samples were subjected to the Charpy test using a pendulum impact tester. Each composition was evaluated with five unnotched samples measuring 80 mm × 10 mm in thickness. The energy required to break the specimens and the roughness of the composites can be determined. Figure 2 shows the schematic view of impact testing machine.

3. Results and Discussion

3.1. Tensile Strength. Composite specimens were tested for tensile characteristics using tensile strength and tensile modulus. Different layering sequences of ramie–hemp hybrid composite materials have been put to the test till the samples fail. To illustrate the load–extension relationship for various stacking schemes, the hybrid composites in Figure 3 are shown. They were utilized to determine the composites' ultimate tensile strength and modulus. The point of eccentricity from span reveals the failure start in ramie layers, and all curves exhibit nonlinear behavior. Sample H/R/H (hemp/ramie/hemp) has a somewhat higher tensile strength than the R/H/R composite (8%). Hybrid composite H/R/H has a slightly higher ultimate tensile strain than hybrid composites

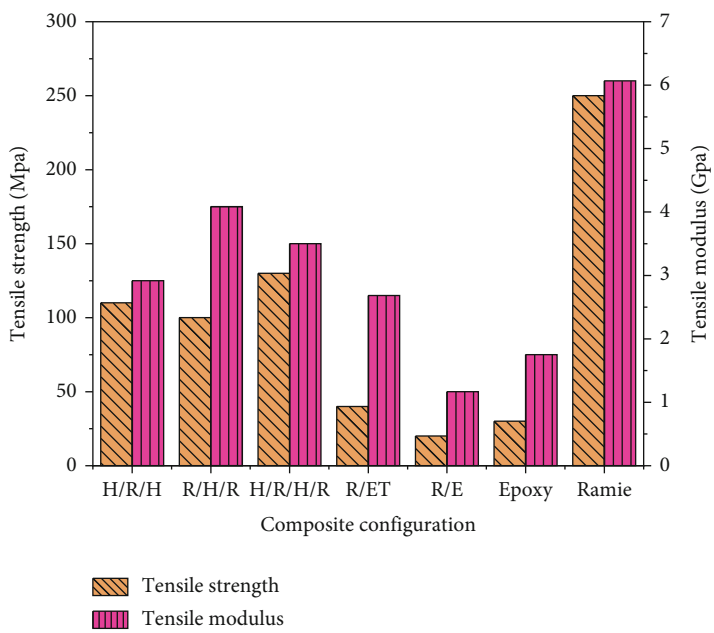

Figure 4: Tensile strength and modulus of R/H hybrid composites, R/E, pure epoxy, and H/E.

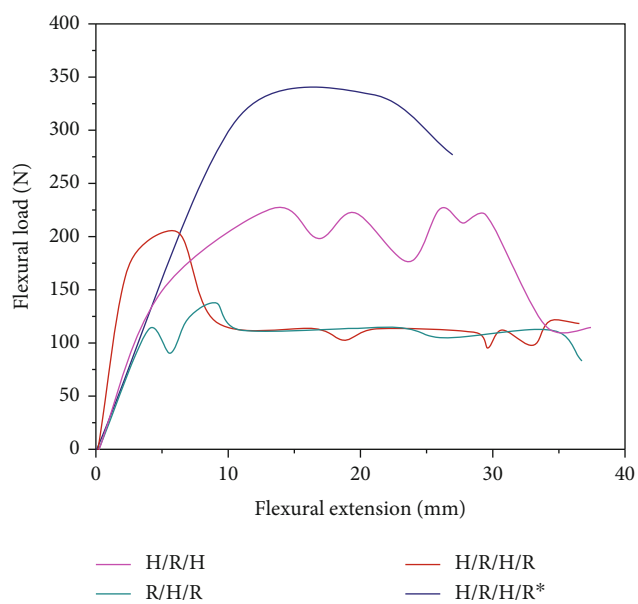

Figure 5: For hybrid composites, the flexural load–extension curve.

R/H/R and R/H/R/H. Weaving ramie woven layers with lower strength on the inside and higher-strength fabric on the exterior may help improve the composites tensile strength. Fiber content in the fibers of three- and four-layer hybrid laminates was practically equal in this investigation. The average tensile strength of samples with 3-layer hybrid laminates was 99.4 MPa, according to the results. Hybrid laminate products have an overall strength of around 123 MPa. When one more hemp-based layer is added, it enhances the overall tensile strength and modulus (R/ET) of the 4-layer hybrid composite, which is superior to non-treated ramie and epoxy (R/E), and it is shown in Figure 4. For example, alkaline treatment increases fiber surface adhesion properties by eliminating both natural and manufactured contaminants from the fibers, resulting in better fiber matrix interaction and better fiber integration.

3.2. Flexural Strength. The flexural strength of laminated composites determines how much bending they can take before breaking. Figure 5 shows the flexural load–extension curve. The diagram depicts typical load–extension curves for various stacking sequences. It was also compared to epoxy matrix material and combinations of ramie with epoxy and hemp with epoxy. The hemp–epoxy composites were substantially stiffer and stronger than the ramie–epoxy composites, as shown in this graphic. The curves show that ramie/epoxy composites may sustain more stress before breaking. For sample H/R/H/R/H/R, two distinct curves were produced depending on the loading surface.

Figure 6 shows the mean flexural strength and modulus values for each of the various composite materials. Flexural strength and modulus were the lowest in ramie/epoxy composites, highest in hemp/epoxy composites, and intermediate in hybrid composites, as expected. The flexural properties of hybrid composites are influenced by the number of woven layers that are used. Ramie–hemp hybrid laminates with 3 and 4 layers had similar flexural properties, while the 4-layered ramie–hemp hybrid laminate had superior properties. The order in which the hemp and ramie fibers are layered affects the hybrid composite's properties.

In the case of the sample H, the hemp surface was loaded, whereas the ramie surface was loaded for the sample A. There are 64.7 MPa in tensile strength, and 529 MPa in modulus, of the hemp-surfaced hybrid sample under load compared to the sample H/R/H. Flexural characteristics are better in hybrids that have high-strength fibers on the outer. According to [39], the same thing happened. Flexural

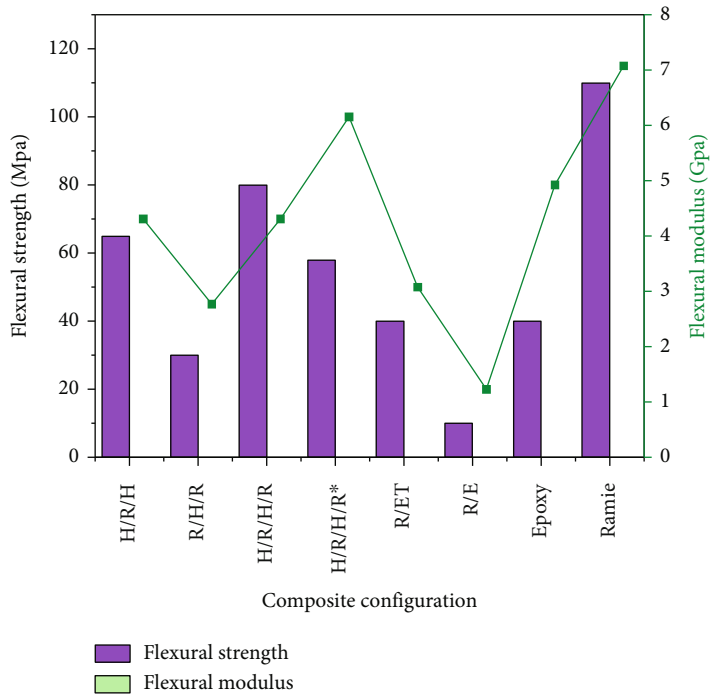

Figure 6: Flexural strength and flexural modulus of R/H hybrid composites, R/E, pure epoxy, and H/E.

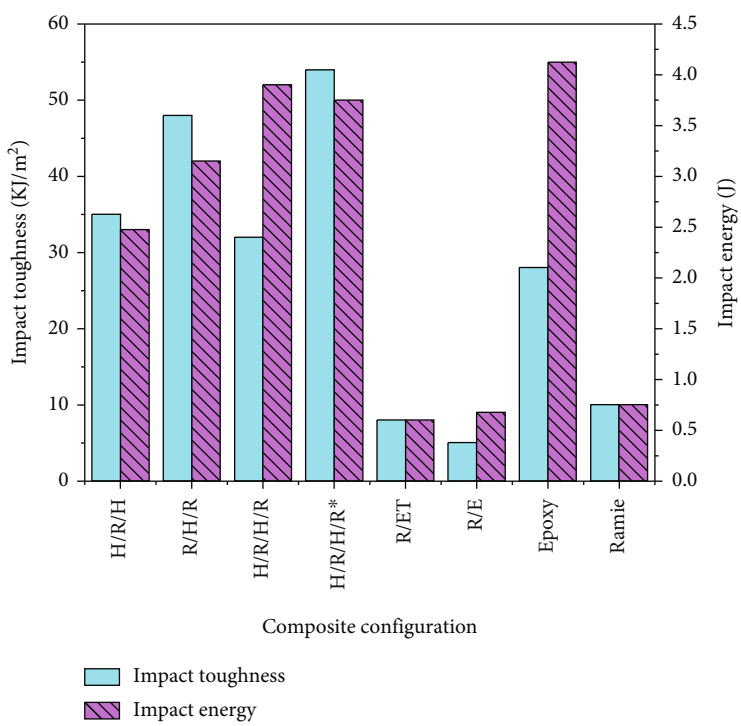

Figure 7: Impact energy and toughness of R/H hybrid composites, R/E, pure epoxy, and H/E by Charpy impact tests.

properties are slightly better in the treated ramie/epoxy weave than the nontreated ramie weave. When it comes to flexibility, sample R/ET has flexural strengths of 52.34 MPa and 287.52 MPa, while the other sample, H/E has strengths of 22.06 MPa and 718.04 MPa. Weaved ramie may benefit from mercerization with 6% NaOH, according to these studies. Chemical therapy for ramie/epoxy was also mentioned by [40]. Reducing the amount of voids in the composites by chemical treatment may lead to a finer weave of ramie, which allows more resin matrix to penetrate the weave and

reduces the overall thickness of the composite, as stated in [41].

3.3. Charpy's Impact Strength. The fiber layering order had an effect on hybrid composites energy absorption capacity, which was tested using the Charpy impact test. The absorbed impact energy is the entire amount of energy necessary to fracture the specimen (J). The difference in potential energy between before and after the test is utilized to calculate it. In order to calculate the composite toughness or impact strength (kJ/m), the measured absorbed impact energy was divided by sample cross-sectional area. Figure 7 depicts Charpy's impact test on ramie–hemp hybrid composites. Hybrid composites' impact energy and toughness responses were clearly visible.

With a 3.97 J impact energy and a maximum impact toughness of 50.1 kJ/m^2, the sample H/R/H/R was found to have the best impact characteristics. With the exception of sample H/R/H/R, 4-layer hybrid laminates surpass 3-layer hybrid laminates in terms of Charpy's impact properties. Surface failure phenomena influenced by ramie, such as fiber breakage, delamination, and fracture initiation, could explain why sample H/R/H/R has lower impact energy and impact toughness. The sample with the hemp layer in the middle outperformed the sample with the ramie layer in the middle in 3-layer hybrid laminates. Because ramie fibers degrade faster than Hemp fibers, this is the case. In sample R/ET, there were signs of chemical treatment. The treated sample (R/ET) absorbed impact energy at a lower rate than the untreated sample. The treated ramie/epoxy (R/E) samples had the same impact toughness as the untreated controls.

4. Conclusions

The effects of woven ramie–hemp hybrid composite stacking and chemical treatment are investigated in this study. The stacking sequence affects the tensile, flexural, and impact properties of ramie–hemp hybrid composites.

(i) In hybrid composites, hemp skin layers exhibit superior flexural properties in tension than ramie skin layers. It had greater tensile strength than three-layer samples. The tensile strength of composites made with treated woven ramie is greater. The hybrid composite with hemp skin layers is marginally more resistant to deformation in terms of tensile strength

(ii) In terms of flexural strength, the ramie–hemp hybrid 4-layer laminate outperformed 3-layer samples. Treated woven ramie improves the flexural properties of woven ramie/epoxy

(iii) The hybrid composite containing ramie skin layers outperforms a sample made from hemp skin layers in terms of impact properties. When it was loaded, sample R/H/R/H had a minor influence on the ramie surface. The results were virtually unaffected by chemical treatment

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Mechanical Behaviour of Alkali-Treated Fabric-Reinforced Polymer Matrix Composites

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Polyethylene (PE) was used as a composite material to create a fabric containing 40% pineapple, 30% jute, and 30% cotton fibres by weight. The physical characterisation is carried out, like deterioration and water absorption tests. PE-based composites were shown to have a lower water absorption rate when dipped in deionized water to perform an absorption test. Fabric/PE composites decomposed slowly in the soil during the degradation test. Alkali solution of 5 percent, 7 percent, and 9 percent sodium hydroxide by weight for 60 minutes was studied as alkali impact mechanical characteristics: mechanical testing's like tensile strength and modulus, elongation at break, bending strength, and modulus. Data investigation exposed that the tensile strength and modulus, elongation at break, bending strength, and composite modulus values were 64 MPa and 871 MPa, 23.14 percent, 45 MPa, and 512 MPa. There were tensile strength and modulus, elongation at break, bending strength, and modulus of the neat polyethylene sheet that were 32Mpa and 342 MPa, 79 percent, 22 MPa, and 234 MPa, respectively. Compared to a polyethylene sheet, composite values for tensile strength and modulus, bending strength, and modulus raised by 107%, 156%, 110%, and 115% as a result of fabric reinforcing.

1. Introduction

Because natural fibre is biodegradable and environmentally beneficial, composites made with natural fibres have been of tremendous interest. Composites are both cheap and environmentally friendly [1]. Fibre-reinforced materials (FRM) have long been known for their advantages over unreinforced materials, and their usefulness in a variety of industries has led to their widespread use. There are numerous applications for FRM, including aerospace and construction [2, 3]. Additionally, net or extended continuous fibre-strengthened materials are utilized in the medicinal field.

Natural fibres have shown promising results in reinforcing composites, although synthetic fibres are currently the most used [4–6]. Synthetic fibre-reinforced polymers, in addition to being expensive, can have a detrimental impact on the environment. Natural cellulose-based fibres are being used to alleviate this problem. Natural fibres coupled with thermoplastic materials are becoming increasingly popular in order to achieve both high volume and low cost [7]. Nonpolar thermoplastic material can be used to remove natural fibres' inherent polarity and hydrophillicity. In the absence of environmental impact, these characteristics are not taken into account. Replacement of synthetic fibres with natural fibres that possess similar structural and mechanical qualities is becoming more important to scientists and engineers alike [8, 9]. In addition to considering the suitability of natural fibres, other factors like rate, environmental effect, cleanliness, elasticity, collecting convenience, and accessibility should be taken into account when selecting raw materials. Natural fibres are a long-term option because they are a renewable resource, as well as affordable and hygienic [10]. Processing natural fibres is also cost-effective and gives a wide range of useful mechanical and physical characteristics. Pineapple Leaf Fibre (PALF) is a leftover product from the farming sector that is extensively grown throughout Asia [11, 12]. Pineapple is one of the few tropical fruits that is absolutely required (Ananas comosus). Because of the fruit's high commercial worth, pineapple leaves can be used to make natural fibres. Its chemical composition is holocellulose (70–82%), lignin (5–12%), and ash (1.1 percent). Since holocellulose makes up a larger fraction of this material, its mechanical qualities are exceptional [13]. Consequently, reinforced polymer composite manufacturing can benefit from its use. Several Asian countries, such as China, India, Pakistan, and Bangladesh, produce a significant amount of cotton [14]. Ninety-four percent of cotton fibre is made up of cellulose. Cotton fibre strength is affected by microfibril alignment, chained molecular weight, highly crystalline purity, and microfibril convolution angles. As another significant natural fibre, jute is produced in a number of countries and regions around the world, primarily in Bangladesh and India [15, 16]. Clothing, ropes, purses, and floor mats are just a few of the items made from jute fibre. It may also be used as a reinforcing agent for polyethylene and other hydrophobic composite specimens, such as low-density polyethylene and unsaturated polyester resin [17–20].

In addition to being lightweight, lucrative, and less in mass, it has other advantages. It also possesses a low elongation at break, a high tensile modulus, and excellent availability. The alpha-cellulose that makes up 82 percent of the holocellulose is responsible for the fibre's outstanding mechanical properties. Jute and cotton fibres were utilized in order to create a low-cost, lightweight composite [21, 22]. Polyethylene has been utilized extensively with natural fibres in the manufacture of composites. Polyethylene (PE) is a thermoplastic amorphous polymer widely utilized in engineering because of its many desirable properties, including its more heat deformation temperature, its spark resistance, and its more impression strength. When it comes to other applications, PE is versatile [23, 24]. The potential of polyethylene composites including natural fibres is growing by the day. Fabric-reinforced partly biodegradable composites were tested for mechanical and degradation properties. Alkali effects on composite and water uptake profiles were also examined [25–27]. Thus, our goal is to create a fabric having 40% pineapple, 30% jute, and 30% cotton fibres by weight and then immerse the composites in 5%, 7%, and 9% sodium hydroxide to assess mechanical properties. Physical characterisation is carried out, like deterioration tests and water absorption tests.

2. Materials and Methods

2.1. Materials and fabrication. The cloth had a thread count of 52 threads per square inch in the warp and 40 threads per square inch in the weft directions. The local market provided the alkali (NaOH) and the PE granules. Polyethylene granules are a robust, thermoplastic substance that is still widely utilized in commodities as well as the food sector. PE's chemical formula is (C2H4)n. Two plates of a heat press machine were used to press polyethylene granules into sheets. An industrial heat press machine was employed for 5 minutes at 180°C with a weight of 2000 kg. The heat press machine was used to chill the sheets as shown in Figure 1. The precut PE sheet and cloth were used for composite manufacturing. Fabric was sandwiched between two sheets of PE, and the technology for producing PE sheets was used to construct composites [28]. Thirty percent of the composites' weight was made up of textiles.

2.2. Mechanical Properties of Composites. With an initial clamp spacing of 20 mm and a tensile and bending force of 10 mm/min, the Hounsfield series testing equipment was used to measure the composites' strength and the setup is shown in Figure 2. It determines the amount of force necessary to fracture a composite material as well as the elongation of the specimen. Material dimensions were $60 \times 10 \times 1.60\,\text{mm}^3$ for the fabric/PE composites. For three days prior to testing, the test samples were kept at a temperature of 25°C and a moisture of 50%. According to the vertical warp direction, mechanical tests were conducted. At least five samples were used to calculate the average of the results for each test value.

2.3. The Composites' Water Absorption Profile. Polymer composite-bonded utilizing natural fibres seem to be susceptible to external factors like moisture. Water absorption studies are performed to assess how much water is added at specific settings. ASTM D-570 was used to evaluate the fabric/PE composite for water absorption. Three fabric/PE composite specimens (specimen 1, specimen 2, and specimen 3) were tested for water absorption. At 25 degrees Celsius (room temperature), specimens of the mixtures were weightage and placed in glasses with 500 mL of deionized water for an hour [29]. The specimens were then removed from the glass, wiped with paper towels, and reweighed following the time interval. After 40 minutes of testing, there was still no uptake, so we continued the exam for an

Figure 1: Hot press machine setup.

additional hour, in accordance with the following procedure:

$$\text{Water absorption (\%)} = \left[\frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}}\right] \times 100. \quad (1)$$

Chemical treatment is amongst the most effective procedures for removing compound organic materials. The major processes involved in alkali treatment seem to be solvation and saponification, which cause particulate organics to expand, making the cellular components more vulnerable to enzymatic assault and so enhancing the biodegradability of the solid phases. Using alkali to test the composites' effects on alkali was done. For 24 hours, aqueous solutions of 5%, 7%, and 9% sodium hydroxide (NaOH) were applied to the composites. It took 24 hours to eradicate the NaOH from the specimens by washing them in water. After that, they were dried for an hour at 70°C to determine their mechanical qualities. The mechanical characteristics of the composites were evaluated by soil dilapidation experiments after a given amount of time in contact with the soil [30]. The fabric/PE composites were subjected to a soil degradation test lasting up to 24 weeks. For a variety of lengths of time, soil samples were placed in a variety of composites. Samples were carefully removed after a three-week period. Tensile and bending characteristics of the specimens were computed after they had been washed and dehydrated at 25°C for one day.

Figure 2: Tensile test analysing machine.

3. Results and Discussion

3.1. Mechanical Characteristics of Composites. Data on the mechanical characteristics of PE matrix and fabric/PE composites can be found in Tables 1 and 2 of this paper. For example, a sheet of polypropylene has 32 MPa tensile strength, 342 MPa tensile modulus, 79% Eb percent, 22 MPa bending strength, and 234 MPa modulus bending. There were TS, tensile modulus, BS, and BM of 64, 871, 45, and 485 MPa for the fabric/PE composites. Concluded matrix PE, PE composites made from pineapple leaves, cotton, and jute fibres received a 107% rise in TS and a 101% rise in bending strength [31]. TM and BM on the other hand showed a 156 percent and 115 percent increase in performance over the matrix material PE, respectively.

There were noticeable improvements in mechanical properties in the 30 percent fabric/PE composite after analysing the data. However, when compared to PE, the Eb percent was substantially lowered. Researchers said that PALF/PE composite (30 percent fibre content) had the following properties: TS, elongation break %, bending strength, and BM of the Pineapple Leaf Fibre/PE composite (30%fibre content), respectively [32]. The inclusion of jute and cotton fibre lowered the mechanical characteristics when compared to the current investigation. The inclusion of jute and cotton fibre reduced stress in the matrix PP, changing its

Table 1: Tensile characteristics of polyethylene (PE) and fabric/PE composites.

Materials	Tensile characteristics		
	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)
Polyethylene	32 ± 1.8	342 ± 28	79 ± 4.87
Fabric/ polyethylene	64 ± 3.24	871 ± 62	23.14 ± 1.9

Table 2: Bending characteristics of polyethylene (PE) and fabric/PE composites.

Materials	Bending characteristics	
	Bending strength (MPa)	Bending modulus (MPa)
Polyethylene	22 ± 1.51	234 ± 19
Fabric/ polyethylene	45 ± 2.82	512 ± 29

mechanical properties. Sandwich construction had a considerable impact on the mechanical characteristics of this material because of the core layer (fabric). The results of this study showed that PE composites based on pineapple leaf, cotton, and jute fibres had mechanical property values that were more than double those of the matrix material alone. Pineapple, jute, and cotton fibres' cellulose content proved advantageous in this situation.

3.2. The Composite Water Absorption Profile. The water absorption capabilities of the composite were demonstrated using the absorption test. Figure 3 shows water absorption measurements on three samples of fabric/PE composites across time and temperature. When the soaking time was increased to 40 minutes, the amount of water absorbed increased to the point where no more water could be absorbed. [33]. The fabric/PE composite was found to have a water absorption rate of 1.6%. No further water absorption was observed after 50 minutes of incubation, and water uptake percentage was 1.46 percent for the PALF/PE composite (30 percent fibre content). Due to the varying fibre composition of the fabric/pp composite, little fluctuation was seen.

The fibre cellulose contains hydroxyl (–OH) groups, which are accountable for water absorption. The sturdy hydrophilic nature of fabric can be illuminated by the occurrence of hydroxyl (–OH) groups in the fibre. Polyethylene, when sandwiched between polyethylene sheets, is very hydrophobic and resists water penetration when used to fabricate composites [34]. As a result, fabric/PE composite water uptake values were lower than they should have been. The strong hydrophilic characteristic of the fabric is due to the cellulose in the fabric. Fabric can be sandwiched between two Polyethylene sheets to keep water out of composites because polyethylene is highly hydrophobic in nature. The cut edge of the composite absorbed water, lowering the water uptake values of the fabric/PE composite.

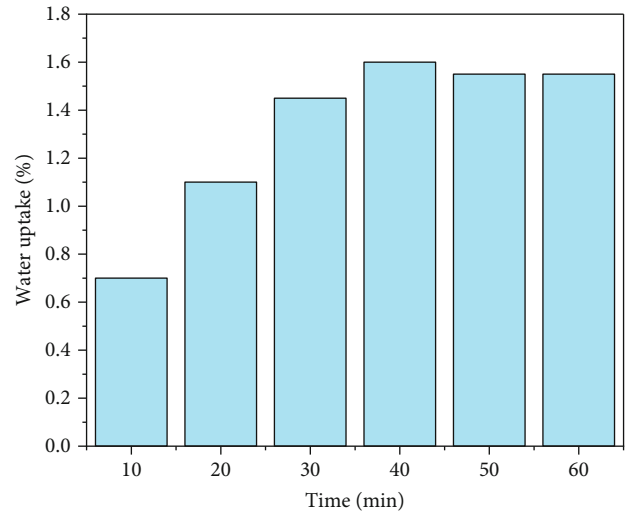

Figure 3: Water uptake % of fabric/PE composites.

3.3. Effect of Alkali. An alkali test on composites (5%, 7%, and 9% NaOH) was passed out for 24 hours at room temperature. It is easy to see in Figure 4 that shows how much the material can stretch before it breaks, how much it can bend, and how much it can elongate before it breaks. Mechanical characteristics in fabric/PE composites deteriorated in all circumstances of the analysis. As demonstrated in the figures, the mechanical characteristics of the mixtures were suggestively reduced where the mixtures were processed with a 9 percent NaOH solution. TS, TM, Eb percent, BS, and BM levels dropped by 23 percent, 31 percent, 34 percent, 25 percent, and 29 percent, respectively, following 24 hours of 9 percent alkali treatment. To increase the mechanical characteristics of natural fibre, which contains cellulose and is alkali treated, the crystal structure of fibres was considerably improved. However, the mechanical characteristics of the natural fibre-strengthened mixtures changed when they were exposed to alkali. Mercerization is a good explanation for the change in mechanical characteristics. Over time, the fabric may have lost its elasticity. Composites become more prone to breaking as a result of mercerization.

3.4. Composite Degradation Test in the Soil. For up to 24 weeks, the composites were exposed to soil degradation tests. There are six measurements presented in Figure 5. The TS, tensile modulus, and Eb% of the fabric/PE composites dropped over time as seen in the figures. Over 24 weeks of soil deprivation, the tensile strength, TM, and Eb percent consumed by fabric/PE composites were 48 percent and 49 percent, respectively. The BS and BM dropped in a similar manner, as seen in Figure 4. After 24 weeks, soil degraded the fabric/PE composites by 45 and 47 percent of their starting BS and BM rates, respectively. Fabric/PE composites, on the other hand, lost about 40% of their mass over the course of 24 weeks. Pineapple leaf, cotton, and jute are examples of natural biodegradable fibres that absorb water quickly due to their hydrophilic nature. In soil, cellulose has a remarkable ability to break down. PE is a hydrophobic material by

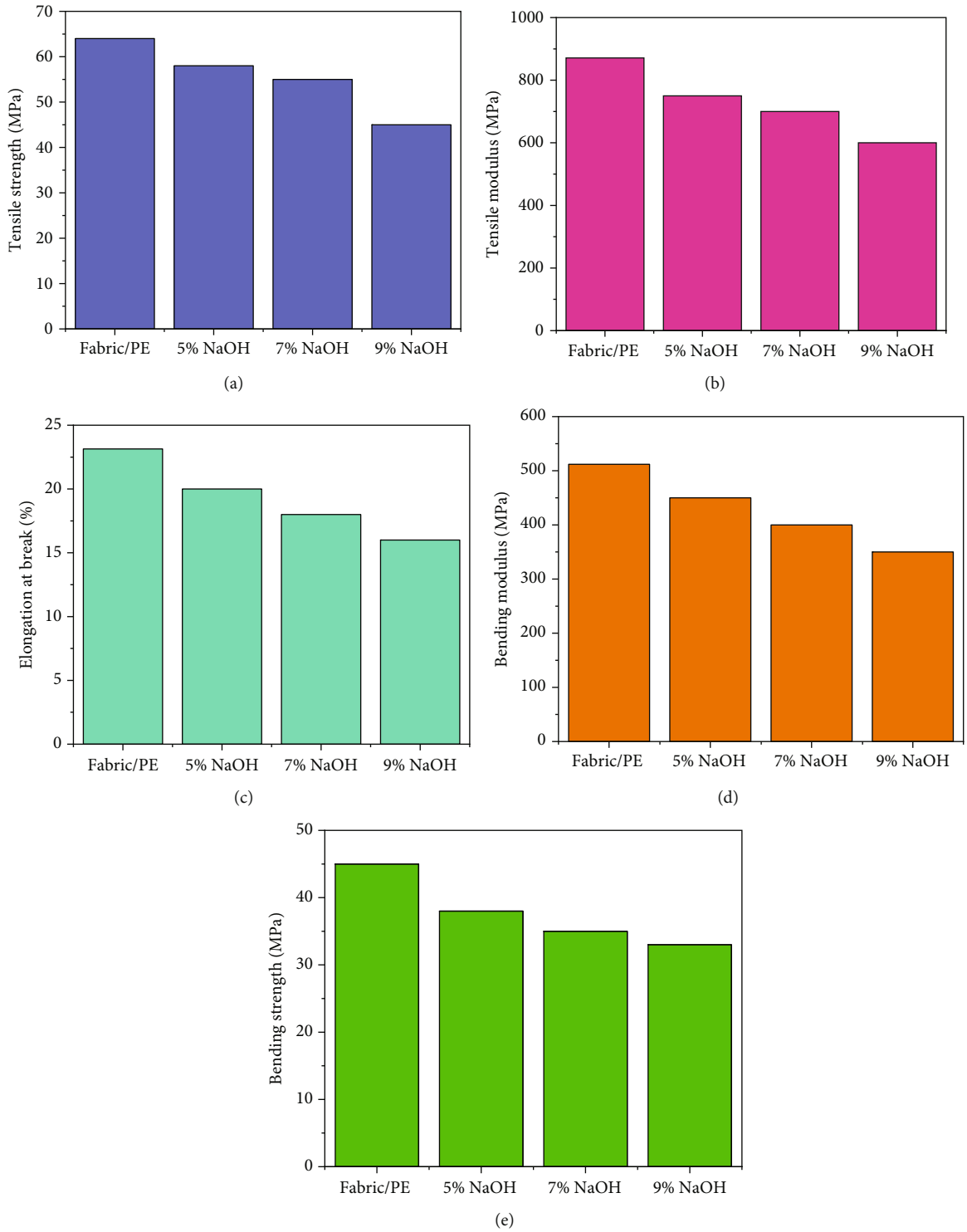

Figure 4: Alkali's effect on the composites' mechanical characteristics: (a) tensile strength, (b) tensile modulus, (c) elongation, (d) bending modulus, and (e) bending strength.

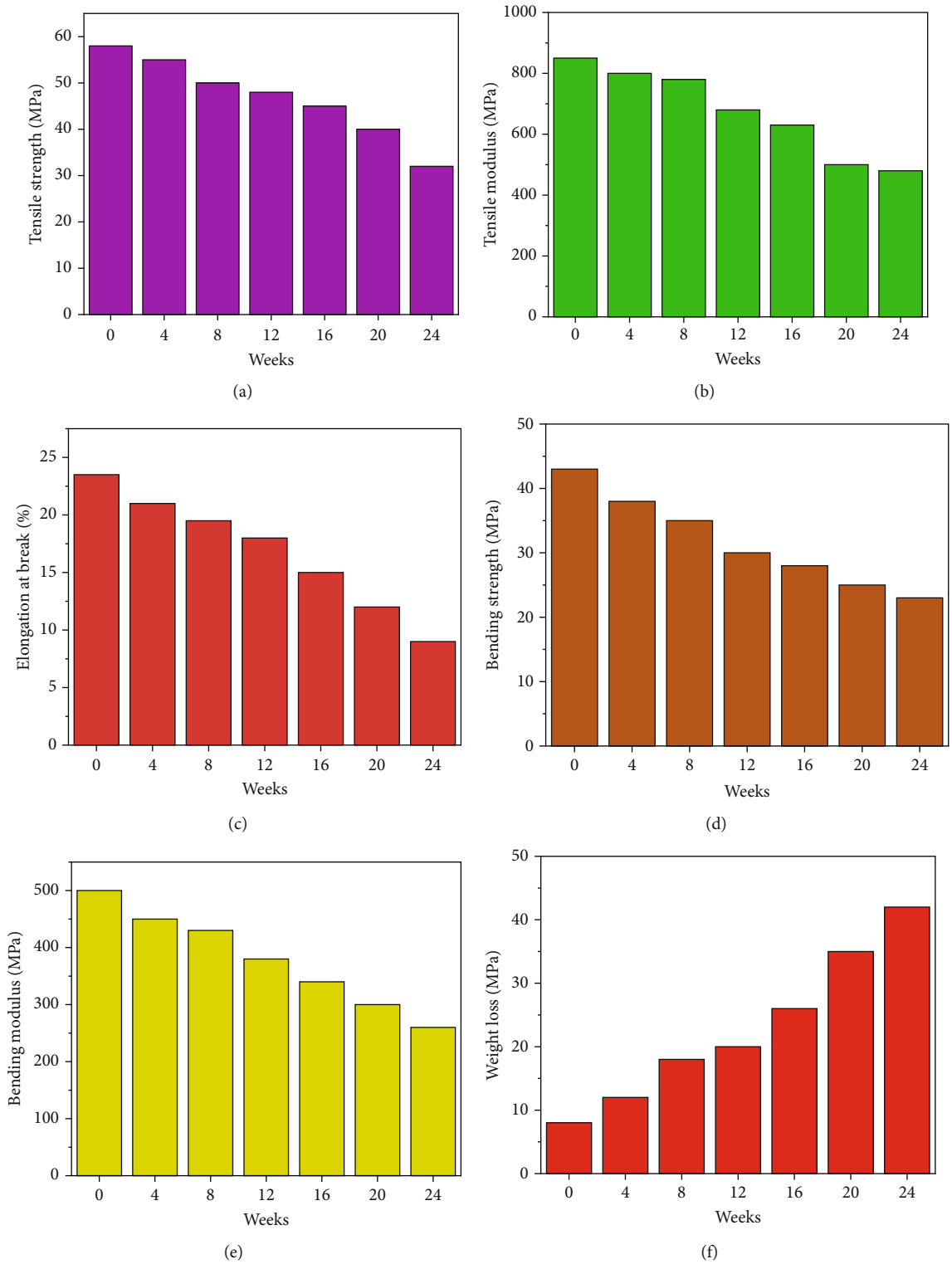

Figure 5: A soil degradation testing of the composites: (a) tensile strength, (b) tensile modulus, (c) elongation, (d) bending strength, (e) bending modulus, and (f) weight loss.

design. While the soil degradation tests, water seeped into the composites through the cut edges, degrading the cellulose and reducing its mechanical characteristics significantly. A 24-week soil degradation test of a natural fibre (jute fibre) strengthened PE-based composite (50 percent fibre weight) showed that 40 percent, 46 percent, 36 percent, and 35 percent, respectively, were lost. After soil degradation testing, the tensile characteristics of the soil have not changed much. However, variations in the fabric/PE composite's fibre % and mix resulted in some bending property changes.

4. Conclusions

Fabric-reinforced successfully manufactured and characterised polyethylene-based composites were obtained. The composite material's mechanical properties were designed to be improved in evaluating the composite material.

(i) There was an improvement of 107% and 156% in the fabric/PE composite TS and TM compared with the PE matrix (64 MPa and 871 MPa, respectively).

(ii) The BS and BM values observed for fabric/PE composites were 110 percent and 115 percent greater than those found for the matrix material, respectively, at 45 MPa and 512 MPa

(iii) When jute and cotton fibres were added to a composite, the mechanical characteristics decreased, but water uptake remained relatively stable

(iv) The mechanical characteristics of fabric/PE composites were lowered by alkali. Six months of soil degradation testing of the fabric/PE composites showed that the composites kept around 50% of their initial mechanical capabilities

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Investigation on Physical and Mechanical Characteristics of Date Palm Fiber Reinforced Aliphatic Epoxy Hybrid Composites

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Automotive industry attention in using date palm fiber as an internal material has been sparked by its use as a polymer reinforced composite. Date palm fiber-reinforced aliphatic epoxy composites for semistructural applications are the key goals of this work. To make the various composites, they used a combination of manual lay-up and adhesive bonding. Date palm fiber/bamboo hybrid composite and uncontaminated composites were tested through density, tensile, flexural, and impact tests and also studied the effects of swelling, water absorption, and physical performance in greater depth. According to studies, hybrid composites constructed from date palm fiber and bamboo had the best mechanical properties. The date palm/bamboo hybrid composite was created to impact the toughness of 12.72 J/m in tensile, flexural strength, and impact toughness measurements. The reduced swelling and water absorption were 27.66 percent and 15.37 percent, respectively, when testing a date palm fiber/bamboo hybrid composite. Density ranged from 1.15 g/cm^3 to 1.25 g/cm^3 for bamboo fiber composite material and from 1.23 to 1.27 g/cm^3 for date palm fiber/bamboo composite material. High flexural strength is achieved by the bamboo composite specimen (bamboo: 6.18 MPa), followed by (PDF-*A*/*B*: 61.12 MPa, date palm fiber-AA/*B*: 61.08 MPa, date palm fiber-*L*/*B*: 60.82 MPa, and date palm fiber-*G*/*B*: 61.47 MPa), and the PDF composite specimens (date palm fiber-*A*/*B*: 61.112). Hybridized materials (date palm fiber/bamboo fiber) with a 50 : 50 ratio had higher impact strength.

1. Introduction

Research into amalgamated materials has grown over recent years, focusing on their mechanical and physical qualities for an extensive variety of applications [1]. Owing to their non-abrasive nature and less power ingesting as well as their high specific mechanical qualities and biodegradability natural fibers including oil and date palm, jute fiber, hemp fiber, kenaf fiber, sisal fiber, glass fiber, and pineapple leaf take numerous compensations for both people and environment [2][3]. Meanwhile, the demand for petroleum-based polymer composites is on the rise across a wide range of sectors and applications. Other than that, petroleum-based materials are not biodegradable, which has a bad effect on the atmosphere and humanoid health [4]–[6].

More and more people are turning to organic materials, such as food waste and agricultural residues, to make products or use them in innovative ways. Many low-to-medium-

impact product applications could benefit from the use of residue or agricultural wastes as a substitute resource. Plant fibers' potential as reinforcing materials for composites made with synthetic fibers appears to be a long-term one [7]. Fibers from the date palm were successfully recovered by chemical degumming and are one of the world's most widely accessible natural fiber kinds. It is used to make ropes, sticks, and roof coverings. Fibers from the DPT are also rich in polysaccharides (44%), cellulosic (28%), hemicellulose (12.5%), inorganic (11.5%), lignin (18.5%), waxes, and fats (18.5%), which have excellent binding capabilities [8].

Date palm fiber reinforced mixture partake has been found to be suitable for an extensive variety of uses, including nonstructural and semistructural interior usage in automobile modules, according to a study by [9]. According to [10], date palm fiber strengthened soil bricks had a higher compressive strength and water repellency than wood chips, which was confirmed in their investigation. In addition to enhancing mechanical and physical qualities, temperature and rheological properties were also affected by the study of particulate date palm fiber. Agricultural waste date palm fibers were shown to greatly improve the bitumen matrices physicomechanical qualities when used as filler in asphalt. Figure 1 reveals the flowchart of applications of polymer matrix composites.

Because of this, the structural properties of a date palm leaf/glass strengthened mixture composites could be improved by alkaline treatment, as demonstrated in [11]. When it comes to tensile strength and modulus, bamboo plant fibers are superior to other natural fibers due to their similar mechanical properties to those of other conventional fibers [12]. Because of its great stiffness, bamboo is regarded as "nature's glass fibre" in Southeast Asia, since that is the most prevalent natural substance fibers. The inferiority microfibril inclination of the fiber axis with a longitudinal direction is also present in bamboo fibers [13, 14]. Relatively dense (1.5 g/cm^3) and mechanical properties like bending load strength make bamboo superior to manufactured glass fibers in many applications.

Lattice platforms made from bamboo have long been used in construction. Using bamboo as an organic filler and thermoplastic composites, a study by [15]–[17] has generated robust natural fiber-based composites materials that are environmentally friendly. Investigation of bamboo fiber wastage and castor liquid polyurethane resin was carried out in comparison to Oriented Strand Board (OSB) [18, 19]. Wear resistance, flexural toughness, and elasticity were all higher in the experimental OSB than in commercial OSB. For example, an individual's specific strength and stiffness are frequently used to measure the mechanical performance of composites made from natural fibers [20, 21]. Similar to cellulose and microfibril angle, these reinforcements have a significant impact on the composite material for a wide range of applications. While natural residual waste can be an ecological sustainability resource and economically feasible for numerous uses, the discovery of biodegradable composite material has highlighted with concern about composite materials substances two or more types of fibers. The characteristics of the two phases are combined in composite materials. Instead, in hybrid materials, the elements join at a molecular level, resulting in an orbital interaction condition. This research is aimed at creating a combination composite material from agricultural waste residue fibers and bamboo fiber attention to the significance of ecologic and material effectiveness [22], whereas the date palm fibers are predicted to be hard and compressive strong, and these materials are predicted to be high in strength [23]. Adhesive matrix composite fiber strengthened with date palm/bamboo waste stains is expected to enhance workability of strengthened date palm trees. Date palm fiber biocomposites mechanical behavior should be improved for non- and quasifunctionalities. Table 1 shows the chemical composition of DPT and BF.

2. Materials and Method

2.1. Materials. Aliphatic is a class of biodegradable implantable polymers. Aliphatic combination composites with a blend of DPF dimensions from 0.8 to 1 mm were used in this investigation. In addition, epoxy resin was used as the matrix resin in the manufacturing of the date-palm/bamboo hybrid.

2.2. Fabrication of Date Palm/Bamboo Hybrid Composites. The simplest molding method for manufacture is hand lay-up. Woven or knitted fibers are initially manually put in the mould. The resin matrix is applied to the reinforcing material using a brush then heated with pressure to make a polymer composite. By using hand lay-up method, researchers created three distinct sample forms: date-palm fiber composite, bamboo fiber composite, and a hybrid date-palm/bamboo composite. Solitary sample is defined as a combination of date palm leaf stalk (*A*), fruit bundle stalk (AA), leaf sheath (*G*), tree trunk (*L*), and bamboo materials. Bamboo fiber is a fantastic material and an extremely eco-friendly alternative to synthetic fibers. It is made from a fast-growing, antibacterial, and deodorizing. In the meantime the, the reinforced date-palm blending consists of date-palm fruit leaf stalk and bamboo (*A*/*B*), date-palm fruit bunch stalk and bamboo (AA/*B*), date-palm leaf sheath and bamboo (*G*/*B*), and date-palm trunk and bamboo (*L*/*B*) mixtures. There are a wide range of date palm fiber/bamboo composites to choose from, each with its own unique chemical components (cellulose, hemicellulose, and lignin) and yield.

In establishing the composite samples, three distinct phases were employed. Components materials were first cleaned and dehydrated at 60°C for 24 hours to decrease humidity to 6*e*8 % before being used. A metal casting mould of 150 by 150 by 3 millimeters will be the next step. Throughout this stage, a 2 : 1 stoichiometric resin-to-hardener ratio was also rippled into the fibers mixture. After being heated to 110°C for 15 minutes and then cooled for 10 minutes with a cold hydraulic press, the very last combination was dispensed into the metallic cast mould and evenly banquet with a 50 : 50 weight proportion of fibers and composite resin. Later, the samples were extracted and sectioned in size-appropriate repetitions for every investigation.

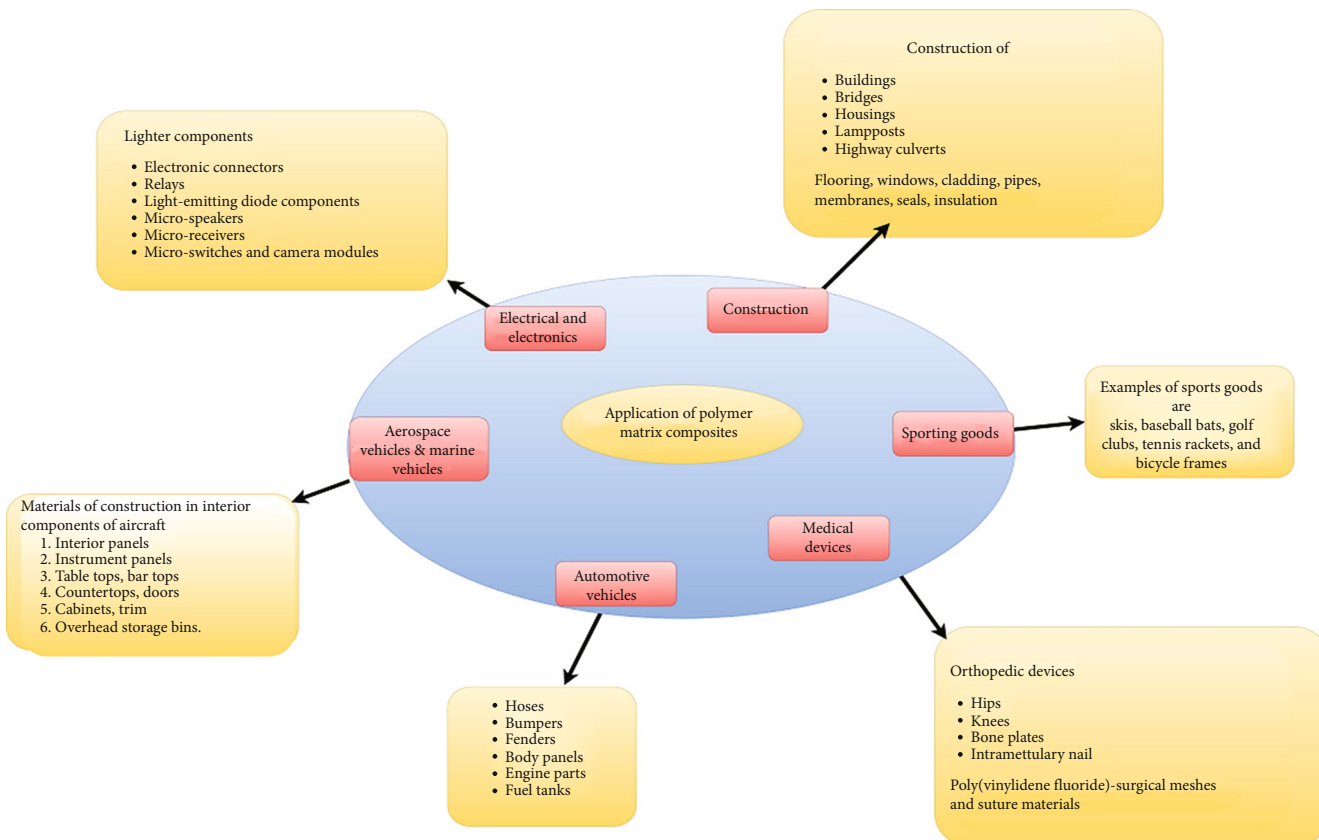

Figure 1: Applications of polymer matrix composites.

Table 1: Chemical composition of (DPT) and (BF).

Specimen	Leaf stalk (A) of date palm fiber	Fruit bunch stalk (AA) date palm fiber	Leaf sheath fiber (G) date palm fiber	Trunk fiber (L) date palm fiber	BF
Cellulose (%)	36.00	45.80	45.65	42.00	74.85
Hemicellulose (%)	16.84	27.50	25.45	11.25	13.55
Lignin (%)	21.65	12.50	19.80	31.25	11.25

3. Analysis of Natural-Hybrid Composite Materials

3.1. Thickness Swelling (TS) and Water Absorption (WA). The thickness swelling (TS) method is used to test the dimensional stability of composite panel materials. A composite structure's mechanical properties have been significantly altered by the physical parameters of thickness swelling. Specimen dimensions for all duplicates were 20 mm by 20 mm by 3 millimeters. Relative water absorption rates were determined using the ASTM-D 570 standard [24] for sample made of hot-moulded epoxy composites. All specimens were soaked in pure water at ambient temp for twenty four hours to conduct a soak test. For seven days, the thickness data of each specimen has been recorded before and after each day. Equation (1) was therefore utilized to calculate the specimen thickness swelling, where T0 represents the specimen thickness prior to soaking and T1 represents specimen thickness following soaking [25].

$$\text{Thickness Swelling}(\%) = \frac{T_1 - T_0}{T_1} \times 100. \quad (1)$$

When it comes to water absorption, the composite specimen used in this investigation passed the ASTM D 570-98 water absorption test. It has been noted that all mixture samples have been verified with their starting weight (W_d) and their final weight (W_n). For the next eight days, the test specimens will be submerged in distilled water. As a result, Eq. (1) has been used to calculate the composites' water absorption value (2):

$$\text{Water absorption}(\%) = \frac{W_n - W_d}{W_d} \times 100. \quad (2)$$

3.2. Density. Based on the composite's strength properties, it has been segmented into min, medium, and max densities. There is a min-thickness reinforced segment, which has greater voids and porosities, which includes materials that can absorb more humidity and retain extra water. The natural material, on the other hand, had a high density and high rigidity due to fiber compaction. It is also worth noting that hybrid fabrics have a tendency to soak up water or moisture. Consequently, the durability of the mixtures was aided by substance load capacity or fiber infusion in the context of hybrid material investigations. As a result, composite specimens were calculated using Eq. (3)'s general composite rule of mixture.

$$\text{Density}, \rho\left(\text{g/cm}^3\right) = \frac{\text{Mass}}{\text{Volume}} = \frac{m}{\text{V}}. \tag{3}$$

3.3. Tensile Properties. A tensile strength test was also conducted as part of composite material research. Figure 2 shows the photographic view of tensile testing machine. The tensile test is a critical test for determining the structural strength of composite materials. Hybrid composite materials' improved mechanical capabilities could be attributed to the natural fiber's higher cellulose content as a whole. In accordance with ASTM D3039 values, the structural characteristics of the test were measured by $120 \times 20 \times 4$ mm for duplicates. In addition, tensile testing can reveal the elongation at break.

3.4. Flexural Properties. Tensile, compressive, and shear material qualities are affected by flexural strength and stiffness. It is necessary to conduct flexure tests on composite materials with whichever a spherical or four-sided cross-section, where the shear stress along the centerline is the failure mechanism. The flexural characteristics of composites have been measured using the ASTM D790 standard three-point bending configuration. A 3 jig with a bend speed of 3 mm/min was used to examine all kind of composite sample with specifications of 120 mm × 20 mm × 3 mm. This equations allows the universal testing machine of 20 kN to calculate the formulas for actual flex strength and modulus.

$$\text{Flexural strength}: \sigma_f = \frac{3P_f L}{2bh^2} \tag{4}$$

$$\text{Flexural modulus}: E_f = \frac{ML^3}{4bh^3} \tag{5}$$

3.5. Low-Velocity Impact Testing. These composite specimens were tested utilizing Izod impact trial equipment under ASTM D256 standard to assess their impact toughness. A total of three composite specimens were made, each measuring $70 \times 15 \times 3$ mm.

4. Observations and Outcomes

4.1. Thickness Swelling (TS) and Water Absorption (WA). Due to exposure of fibers in the materials, there was a significant increase in the composite's overall thickness. As the composite soaks up water, it will expand in size due to the lignocellulosic material's hydrophilic qualities. Because of this, the sample capillary has grown, resulting in a larger sample size. Figure 3 also shows the results of TS vs. absorption duration for DPF, BF, and DPF/bamboo hybrid composite samples. It has also been shown that there are three distinct stages of TS (Figure 3). During the first day of immersion, the thickness swelled dramatically. It takes three days for the second stage of swelling to begin to show signs of thickening. After three days, the swelling has reached a point where it is no longer increasing in thickness.

The bamboo fiber composite (*B*) specimen's TS behavior increased by 16.92 percent, as seen in Figure 1, and was thus reported as having the highest TS qualities. Hybrid composite (*G* / *B*) has a TS score of 13.79 percent, followed by hybrid composite (*A*/*B*) at 12.98 percent, hybrid composite (AA/*B*) at 10.26 percent, date palm fiber composite (AA) at 9.28 percent, date palm fiber (*G*) at 8.94%, hybrid composite (*L*/*B*) at a TS score of 8.49 percent, and date palm fiber (*L*) at 6.54 percent. Initially, after only one day of soaking, there was a substantial rise in swelling thickness. A progressive thickening occurs over the course of three days during this second phase of swelling. Owing to the less hydrophilic character of the materials, the DPF composite had the lowest TS percentage of 6.52 percent. Because of this, the density of DPF/bamboo hybrid composite panels was absolutely connected with the thickness swell dispersion of the polymer. Water uptake or water absorption is another aspect that affects the stability of composite materials. Voids and fiber loading, matrix viscosity, and atmospheric conditions have all played a role in composite material's water absorption.

WA valuation must be carried out to establish the appropriate developments for composite constituents in terms of analyze and enhance their physical and dimensional behaviors. Water absorption percentage (WA) results are shown in Figure 4, with hybrid composite (*G*/*B*) at 12.45 percent, DPF composite (*G*), hybrid composite (*A*/*B*) at 10.73 percent, hybrid composite (AA/*B*) at 10.17 percent, and hybrid composite (*L*/*B*) at 9.78 percent. It was attributed to vacancy contented, fibrous solubility, and the viscous of the polymer matrix that the water absorption rate was higher. WA absorption is also assumed to include the hemicellulose, which is present in the form of small pores and fissures. Palm high hemicellulose content (17.9%) than bamboo (11.2%) and moisture qualities are being improved.

4.2. Density. Natural fiber composite material mechanical performance is mostly determined by density. Natural fiber material's density ranged from 0.5 to 1.5 g/cm^3 to 12.8 g/cm^3 compared to synthetic fiber material's range of 12.8 to 13.6 g/cm^3. According to Figure 5, the density of a single DPF composite material ranged from 1.15 g/cm^3 to 1.25 g/cm^3 for bamboo fiber composite material and from 1.23 to 1.27 g/cm^3 for date palm fiber/bamboo composite material. According to a DPF composite g/cm^3 density, the material is between 1.61 and 1.90. Composite samples examined in this work for their value volume, rigidity, and impacts performance, accordingly.

4.3. Tensile Properties. In the past, tensile toughness of complex materials was used as a measure of their ability to

Figure 2: Photographic view of tensile testing machine.

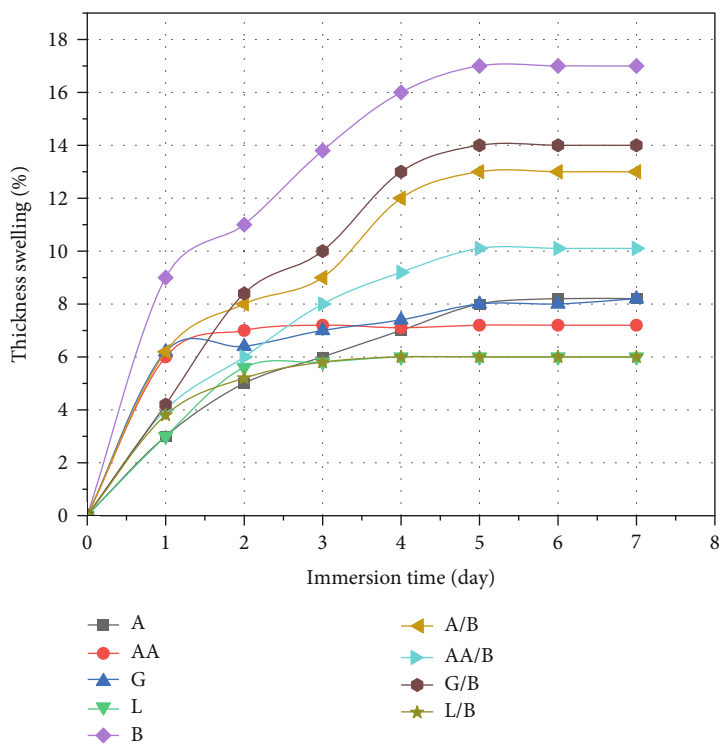

Figure 3: Thickness swelling for DPF and hybrid composites.

withstand longitudinal tensile stress. For the transverse tensile properties of a naturally biocomposite, the adhesive interaction, fiber content ratios, fiber capacity fraction, fiber span, and fiber width of a composite material are critical. Figure 6 shows the ductile features of aliphatic composites strengthened with natural fibers. The tensile properties attributes of DPF extraction and BF are revealed in the results.

Composite specimens made of date palm fiber (DPF) and combination composites were found to have the highest values when it comes to the composite's tensile modulus, as illustrated in Figure 7. Composites using DPF filler and epoxy have a high ductile modulus due of the improved interactions and integrated mixing of the materials. This can be observed in the graph. The high ductile modulus (date palm fiber-*G*: 6.33 GPa, date palm fiber-AA: 5.97 GPa, date palm fiber-*L*: 5.92 GPa, and date palm fiber-*A*: 5.59 GPa) was attributed to the date palm fiber (DPF) specimen.

According to findings, low modulus fibers are more likely to have high elongation values. Polymer composites reinforced with DPF are bonded to each other at the interaction by Saba et al. that revealed a 50% increase in tensile modulus for date palm stem fibers/epoxy evaluated to other

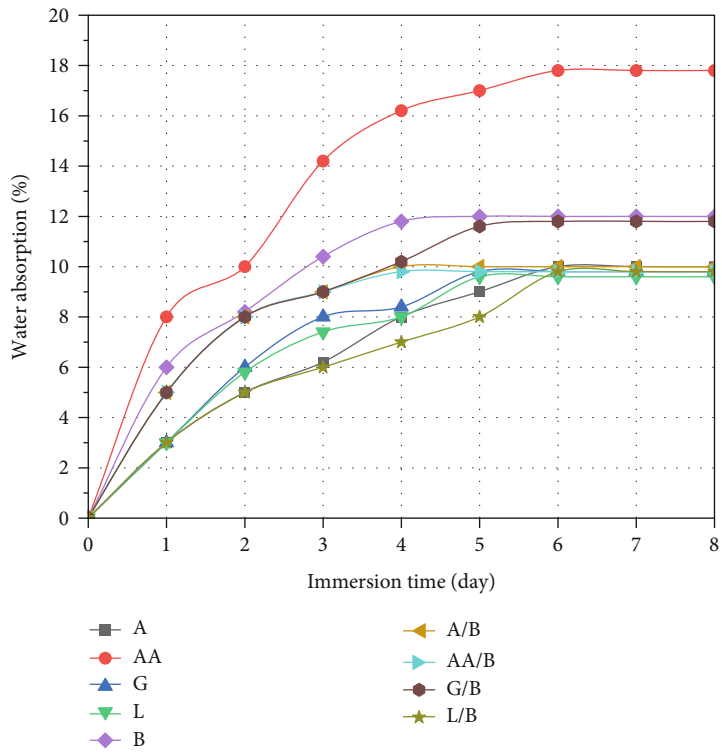

Figure 4: WA for DPF and hybrid composites.

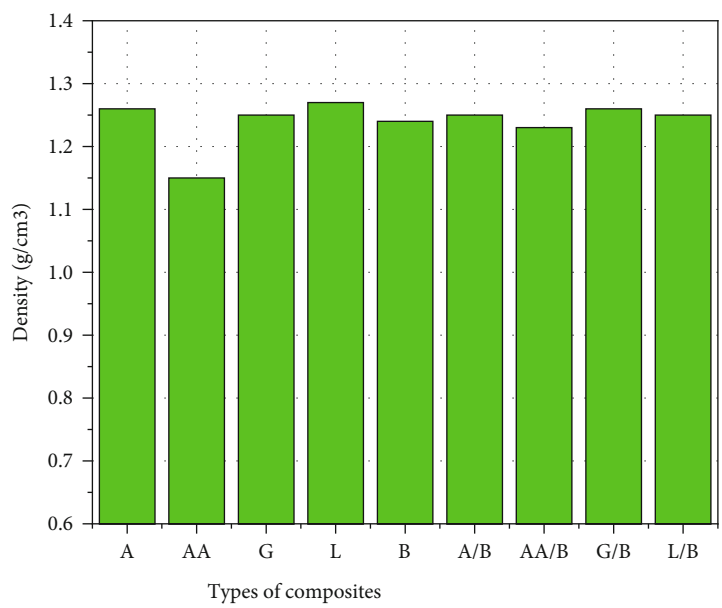

Figure 5: Densities of DPF and hybrid composites.

section of date palm fiber composites. Because of enhanced interactions among the essential resources of natural/natural hybrid composites, as revealed in a study by Ismail and coworkers, tensile characteristics and performance can be improved. To estimate the length at break, it is necessary to conduct testing in tensile mode, which is termed as fracture strain. Figure 8 depicts the natural plant fiber's resistance to length changes in a specific length. The bamboo fiber composite's break elongation (bamboo: 1.02 millimeters), hybrid composite specimens (date palm fiber-*G*/*B*: 0.94 millimeters, date palm fiber-AA/*B*: 0.86 millimeters, date palm fiber-*A*/*B*: 0.77 millimeters, and date palm fiber-*L*/*B*: 0.81 millimeters), and DPF composite specimens were as follows. In the mean time, Figure 6 shows the length at

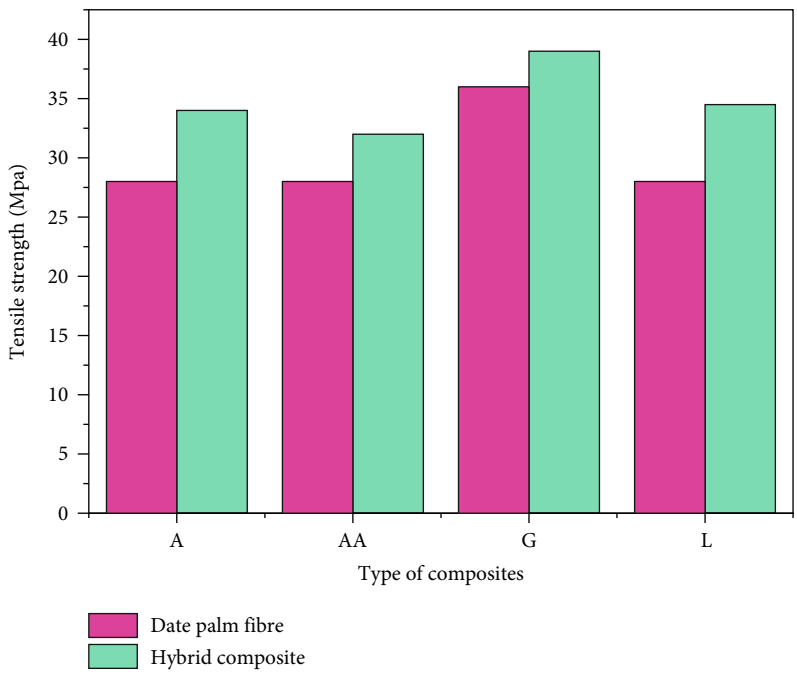

Figure 6: Tensile strength of DPF and hybrid composites.

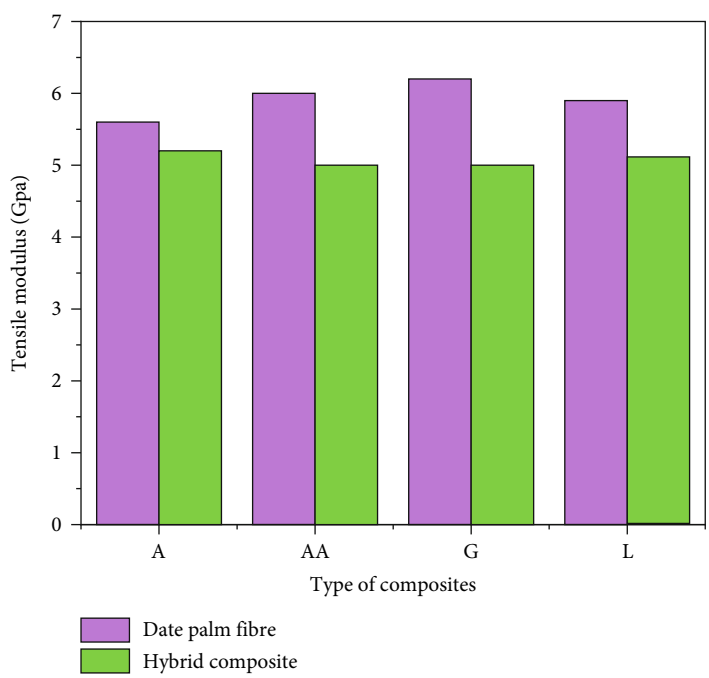

Figure 7: Tensile modulus of DPF with hybrid composites.

discontinuity of BF material (*B*: 1.02 millimeters) and hybrid (date palm fiber-*G*: 0.76 millimeters, date palm fiber-*A*: 0.67 millimeters, date palm fiber AA: 0.64 millimeters, and date palm fiber-*L*: 0.64 millimeters) bamboo filler's extension at intersections in hybridization dates. It is amazing how much palm fiber/bamboo has helped with reinforcement, especially in comparison to higher fiber loadings. To prevent fibers and matrix from slipping, filler particles can be included. This will boost the composite's tensile strength.

It has also been found in a prior study, which found that increased fiber loading at the break point of composite materials can lead to a significantly raised in extension at the point of breakage because of its reinforcing influence on the stress transfer. Modulus of elasticity at the breakage

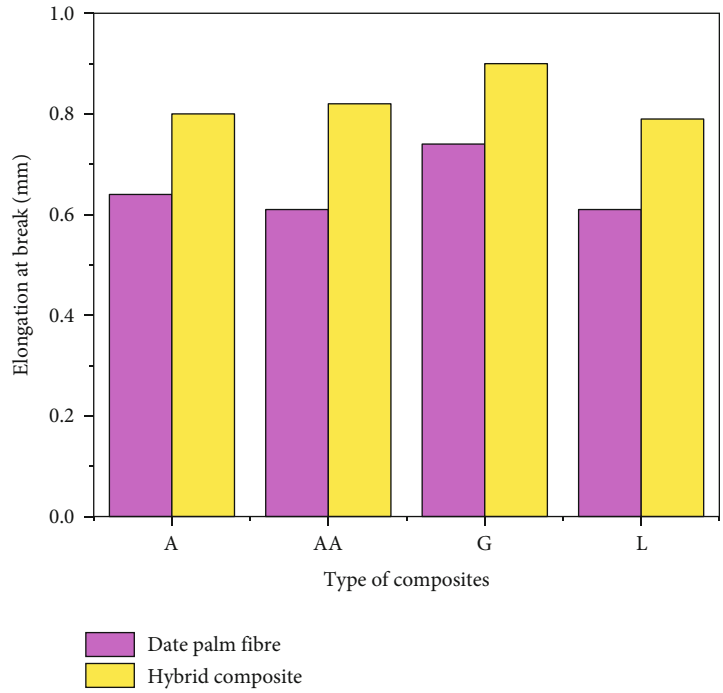

Figure 8: Elongation at break of DPF and hybrid composite fiber.

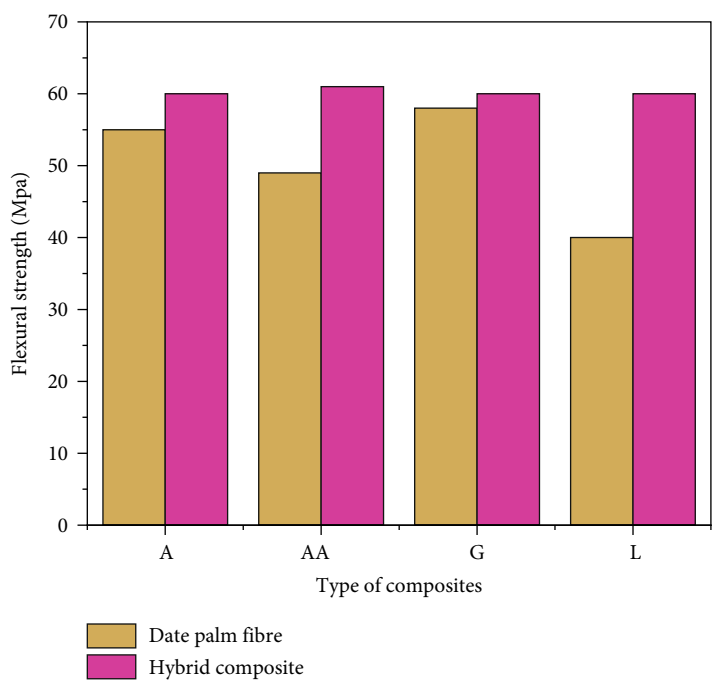

Figure 9: Flexural strength of DPF and hybrid composite fiber.

and tensile is significantly improved in DPF reinforced polymers manufactured from recycled polypropylene, low-density polyethylene (LDPE), and high-density polyethylene (HDPE). The mechanical parameters of tensile roughness, flexural modulus, and percentage of elongation in organic materials can be greatly improved by preparation of wheat straw. In fiber-matrix constituent interfacial bonding, hemicellulose and lignin breakdown straw biomass surface structure plays a vital role along with its porous.

4.4. Flexural Properties. Figures 9 and 10 state the flexural properties of the DPF, BF, and the date palm fiber/bamboo hybridization. As shown in Figure 9, the high flexural strength is achieved by the bamboo composite specimen

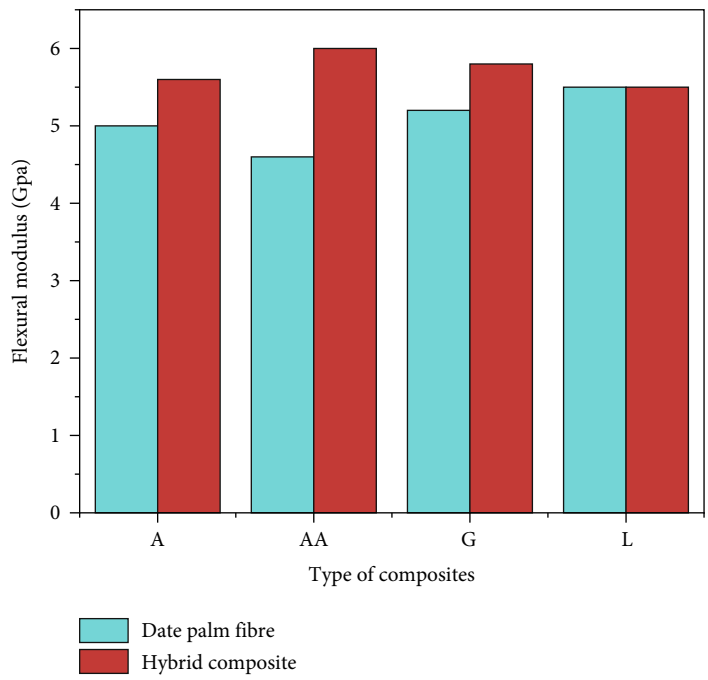

Figure 10: Flexural modulus of DPF and hybrid composite fiber.

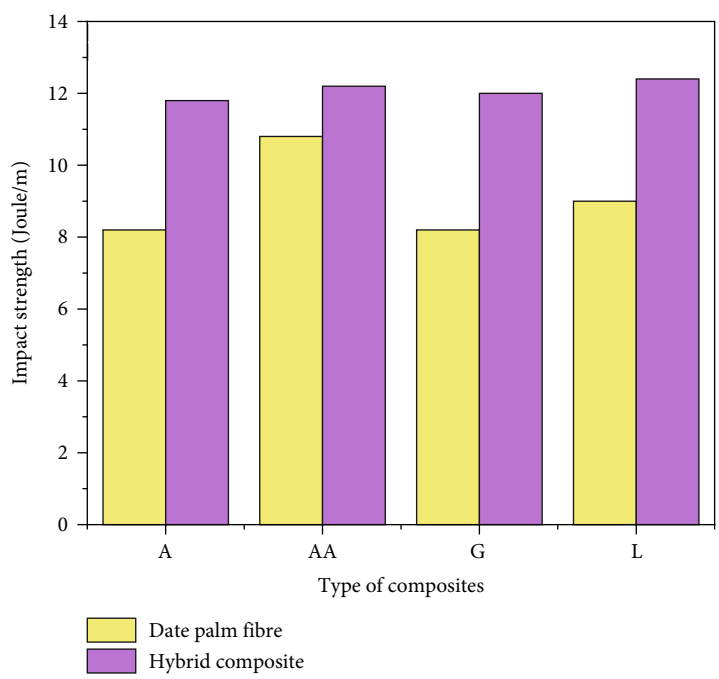

Figure 11: Impact strength of hybrid composites.

(bamboo: 6.18 MPa), followed by (DPF-*A*/*B*: 61.12 MPa, date palm fiber-AA/*B*: 61.08 MPa, date palm fiber-*L*/*B*: 60.82 MPa, and date palm fiber-*G*/*B*: 61.47 MPa) and the DPF composite specimens (date palm fiber-A/B: 61.112). A total of (date palm fiber-*G*: 58.30 MPa, date palm fiber-*A*: 55.25 MPa, date palm fiber-AA: 48.88 MPa, and date palm fiber-*L*: 40.36 MPa).

The flexural strength of the palm/bamboo fiber strengthened-epoxy composites with a 50/50 palm/bamboo fiber-filled composite has been enhanced by hybridization approach. [10] has indicated that the adhesiveness in the hybridizing progression contributes to outstanding flexural properties outcomes in natural fiber hybridization investigations.

Flexural modulus, on the other hand, was a key mechanical property in the investigation of composite stiffness. Figure 10 indicates that the flexural modulus of bamboo composites (*B*: 6.17 GPa), followed by hybrid composites and date palm fiber composite specimens, is higher than that of date palm fibers (date palm fiber-*L*: 5.56 GPa, date palm fiber-*G*: 5.32 GPa, date palm fiber-*A*: 5.07 GPa, and date palm fiber-AA: 4.66 GPa). The ductile modulus of various DP0046 materials has been increased by the use of hybrid composite materials (Figure 9). In comparison hybrid composite, bamboo fiber in the composite ingredient increased flexural strength by 42% and flexural modulus by 33%.

4.5. Impact Strength. The impact test to determine the specimens ability to grip and disperse energy from stimulus and load-bearing force was alternate performance in material attributes valuation. Due to the limited mechanical and physical qualities of natural fibers alone, the resin system was needed to withstand both internal and external forces. Bamboo fiber (BF) composite specimen (bamboo: 13.89 Joule/meter) dominated the impact strength variation, followed by hybrid composite samples (date palm fiber-*L*/*B*: 12.72 Joule/meter, date palm fiber-AA/*B*: 12.35 Joule/meter, DPF-*G*/*B*: 12.11 Joule/meter, and date palm fiber-*A*/*B*: 11.58 Joule/meter) and date-palm fiber composite specimens (date palm fiber-AA: 10.71 Joule/meter, date palm fiber-*L*: 9.19 Joule/meter, date palm fiber-*A*: 8.62 Joule/meter, and date palm fiber-*G*: 8.58 Joule/meter) in Figure 11. In comparison to DPF composites alone, the hybridized materials (date palm fiber/bamboo fiber) with a 50 : 50 ratio have a higher impact strength, as shown in Figure 11. For the hybrid composite ingredient used in this work, the use of BF as a filler contributed to an increase in fiber density, which resulted in superior tensile characteristics.

5. Conclusions

(i) Date palm fibers were employed as reinforcements to investigate the potential of organic waste impurities. Incorporating stronger bamboo fibers into hybrid composite materials has increased their unique features

(ii) Using date palm fiber in combination with other high-quality fiber pitches can yield fewer weight materials for several applications while reducing waste and deposition of agricultural wastes

(iii) Date palm/bamboo hybrid composites have variable mechanical capabilities depending on the chemical constituents of date palm fiber and bamboo fiber

(iv) The splintered surface structure of the hybridized materials demonstrated that bamboo fiber and date palm fiber were well hybridized, with less space among the mixed fiber and composites

(v) The impact resistance of bamboo fiber hybridized with date palm fiber such as *L* is good. Still, the tensile and flexural capabilities of other DPF hybrids such as *A* and *G* are superior

(vi) Studies conclude that date palm/bamboo hybridized composites were discovered to have more excellent properties than a date palm fiber composite that was not hybridized

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Acknowledgments

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Research Article

Mechanical Properties of Polymer Composites Reinforced with Alkaline-Treated Natural Fibre

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The mechanical characteristics of a high impact polyethylene composite (HIPC) reinforced with abaca fibre (AF) are investigated in relation to fibre loading. An alkaline behaviour was used to improve the characteristics of the abaca fibre. With a fibre length of 100 mm, five different fibre loadings of the abaca fibre were used to create the samples of the composite (25, 35, 45, 55, and 65 wt percent). The object was made using compression moulding with unidirectional fibre orientation. The influence of fibre loading was investigated using tensile, hardness, and density tests. In an experiment, it was shown that with 55 percent fibre loading, tensile strength was 312 percent higher than without, and Young's modulus was 545 percent higher than without. While this was happening, the hardness and density of the AF/PE composites were found to be quite similar, with minor increases from 25 wt percent to 65 wt percent AF loading in comparison to the control sample's zero wt percent AF loading. 67.42 Shore-D and 1.014 g/cm^3 are the highest values. The alkaline treatment of the AF/PE composite had a substantial influence on mechanical characteristics, according to the findings.

1. Introduction

Researchers, particularly in the automation, shipping, packing, woodworking, and constructions, have recently shown substantial attention in growth of biodegradable fibre reinforced polymer (BFRP) compound by means of an alternative to traditional materials. Plant fibres' plentiful availability and accessibility are the primary drivers of a growing interest in sustainable technologies [1, 2]. Global warming and the exhaustion of fossil fuels have prompted an increase in interest in organic fibre mixtures as a substitute [3]. Biodegradable composites can be made better by

using natural fibres like those found in plants. Aside from its good mechanical and dielectric qualities, natural fibre composites have other environmental advantages, such as being biodegradable and renewable. The goal of this work is to evaluate a techno-economic feasibility based on environmental effect [4, 5]. They are also lightweight and inexpensive and have a decent specific strength. Nowadays, a wide variety of natural fibres are in wide usage. Rice husk, abaca, bamboo, coir, jute, sisal, kapok, coconut, and oil palm fibres are just a few of the natural composite fibres that have been studied by researchers for their potential application in the industry [6]. Abaca fibre was used as a reinforcing material in this investigation, and polyethylene was used as the matrix.

Lightweight, low-cost, nontoxic, biodegradable, and high specific stiffness are some of the compensations of utilizing organic fibres in trading [7, 8]. In the automobile and aircraft industries, these properties make natural fibre–reinforced composites ideal. Automobiles must be designed in a way so that at least 85% of the vehicles weight age can be reused or reprocessed [9]. Fibre strength is a key consideration for prospective industrial use. Fibre-reinforced composites can be made from natural fibres including sisal, flax, ramie, bamboo, and abaca, which have high tensile strengths [10].

Abaca is valued for its high mechanical strength, salinity resistance, and long fibre length. The use of abaca fibre as a reinforcing ingredient including both thermosetting and thermoplastic polymers has indeed been demonstrated. Bananas of the abaca family are cultivated commercially in the Philippines as a source of income. Tensile strength (500–800 MPa) and modulus (40–60GPa) of Abaca fibre are high. The tensile strength (511–635 MPa) and Young's modulus (9.4–22.0GPa) of sisal fibre. Daimler AG vehicles have been protected using abaca fibre-reinforced composites. To meet the demanding criteria of road transportation, abaca fibres must be resistant to moisture and other environmental factors such as the weather and stone impact [11, 12]. Accurate and efficient commercial use of abaca fibres necessitates knowledge of the fibres' specific physical and chemical characteristics and assembly–function connection. Because of their moisture content and weak interfacial interaction with the matrix material, natural fibres are not ideal for composites [13]. In high-load applications, natural fibres still have not totally replaced conventional fibres. Only sections like as door panels, seats, and other interior panels are commonly made with natural fibre-reinforced composites. Surface modification of natural fibres is becoming increasingly relevant as a result of their enormous industrial potential [14, 15]. More and more studies are being done to progress fibre bond and lessen moisture content, which are two key areas of research in the field of fibre improvement.

For textile and natural composite goods, the use of abaca fibre (AF) as a reinforcing material is highly desirable [16]. As a result, the natural complex specimens manufacturing may diminish contamination, waste management issues, and other environmental difficulties by utilizing AF. Because of its high moisture absorption and low compatibility with various polymer matrixes, the usage of natural fibres has considerable drawbacks [17–19]. The natural fibres' surface can be altered to promote adhesion among the hydrophilic natural fibre and the hydrophobic polymer matrix using an appropriate treatment, such as alkaline treatment or heating. According to [20] findings, alkaline behavior better the composites' ductile toughness and modulus. Abaca fibre from Josapine cultivar through alkaline treatment will be used as reinforcement by researchers in this project in an effort to learn more about the mechanical characteristics of polyethylene composites [21]. Alkaline treatment of AF's surface and fibre extraction was the primary focuses of this study. Tensile stress, hardness, and bulk density of the AF/PE composite have been measured.

Lignocellulosic fibres are those that come from plants. To put it another way, lignocellulose materials include wood, agricultural waste, aquatic plants, and grasses. The composition, characteristics, and structure of plant waste fibres make them appropriate for a variety of applications, including composites, textiles, and paper pulp [22]. Aside from that, plant fibres can be utilized to make everything from fuel to chemicals to enzymes to food. A wide range of fibres from flax to pineapple leaf fibre are utilized in textile and packaging industries as well as in low-cost housing and the papermaking industry, as they are all hard cellulosic fibres. For their high tensile modulus and low deformation upon break, these fibres can be classified as hard fibres [23]. Natural fibres have been the subject of several attempts by scientists and technologists to incorporate them into composites. According to the findings of this study, they exhibit great fracture resistance and good electrical, chemical, thermal, and acoustic insulating characteristics. Cellulose fibres have been used as a cheap, renewable, and ecologically beneficial reinforcement material because of the growing interest in environmentally friendly products [24]. Natural fibres are an attractive alternate to artificial or petrochemical-based fibres because of their inexpensive cost, lighter weight, and lower density.

Abaca is a potential natural fibre reinforcing material since it is both affordable and widely available. Fibres by the pseudostem of the banana plant, sometimes referred to as banana fibres or abaca, have intermediate tensile qualities [25]. Fibrous plants, like as abaca, are common in tropical areas and can be grown as a crop. Currently, abaca fibre is a byproduct of banana farming. There is therefore no additional cost to obtain industrial-grade abaca fibre. [26] Creative use of AF during fortification for curbside automobiles has sparked interest in abaca fibre-reinforced composites recently. Acaba fibre is said to have a high strength-to-rot ratio and has a particular flexural strength that is comparable to glass fibres. In abaca fibre, a number of factors must be considered while designing natural fibre composites. Environmental factors like humidity, sunshine, or bacteria can degrade composites, which is a major concern. Fibres' low resistance to water absorption may have a negative impact on the effective stress transmission from the matrix to a fibre [27]. Due to the importance of understanding the long-term impacts of natural fibre composite water absorption and the durability of composites aged in water, it is imperative that this behaviour be thoroughly investigated.

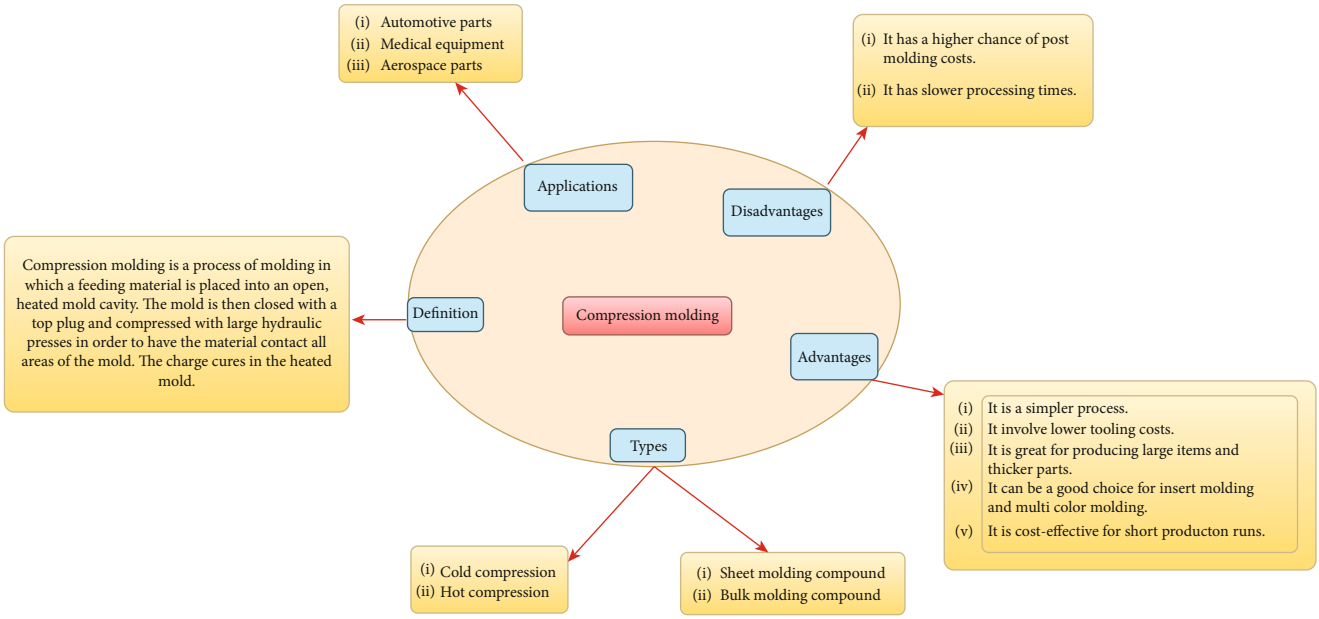

Figure 1: Advantages and application of compression moulding.

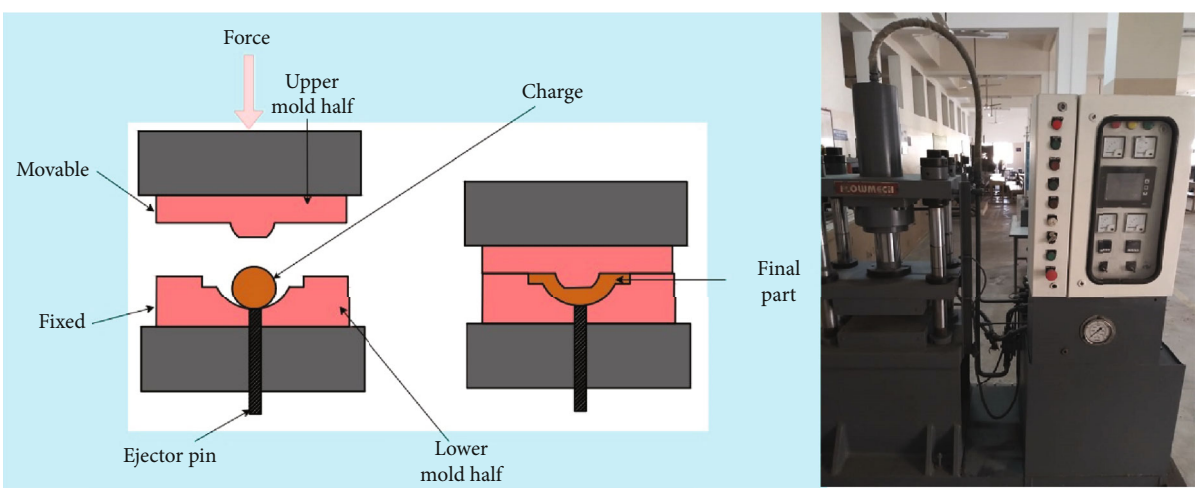

Figure 2: Compression moulding setup.

Because natural fibres are hydrophilic, their inter particle adherence to the polymer matrix is limited, their potential as reinforcing agents is often restricted; chemical modifications are researched to optimise the fibre interface. As a result of chemical changes to fibres, moisture absorption can be reduced [28]. For example, fibres can be treated with alkali or other alkaline agents to lower the moisture absorbed by the fibres. Alkali-treated composites offer improved stiffness, strength, and dynamic flexural modulus, indicating that the matrix and fibres' interfacial bond strength and adhesion have improved. Impurities in natural fibres, such as lignin and pectin, are thought to hinder the fibres' adherence to the matrix during composite construction [29]. In order to improve the interfacial adhesion between the resin and the fibre, natural fibres are routinely treated. Using alkaline treatment to promote fibre adhesion is the cheapest approach, but it reduces fibre strength during treatment, which is a disadvantage.

The water absorption studies of a single abaca fibre are currently unknown. Fibres can be used more effectively in composite materials if we better understand their ability to absorb moisture [30]. Thus, our aim is to study about abaca fibre in detail to see how alkali treatment affected its moisture absorption property in the present work. Figure 1 reveals the advantages and application of compression moulding.

2. Materials and Methods

2.1. Materials. Particles of impact polyethylene are in powder form (250 m). AF was generated in this work using a new extraction method. Fibres were extracted by

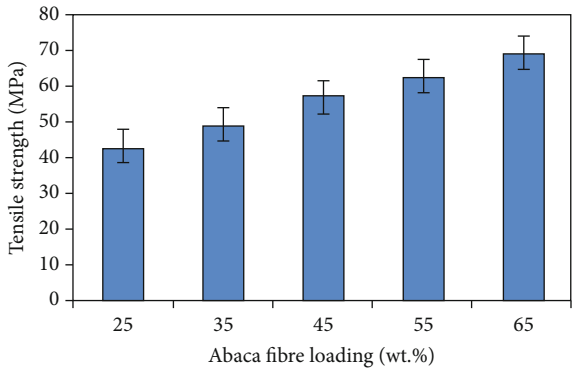

Figure 3: Tensile strength (MPa) vs abaca fibre loading (wt %).

Table 1: The specimens' tensile strength.

Loading of abaca fibre (wt %)	Tensile strength (σ)	Young's modulus ($\boldsymbol{E}$)	Strain ($\boldsymbol{\varepsilon}$)
0	16.1	0.81	0.06
25	43.4	3.10	0.04
35	49.5	3.51	0.045
45	57.1	4.02	0.042
55	62.7	5.12	0.04
65	69.3	3.28	0.06

introducing the abaca into an AFM and let it to spin. Instead of crushing the abaca to remove the waxy covering, this machine employed blades to remove it. Alkaline treatment is a chemical process in which natural fibres are submerged in a high concentration of aqueous sodium hydroxide to cause significant swelling and subsequent changes in fine structure, dimension, and mechanical characteristics over time at a certain temperature. The fibres were alkaline treated after extraction in order to alter their surface properties. For one hour, the fibres were submerged in a water reservoir filled with a 5 percent NaOH solution at room temperature. Before drying at ambient temperature for 48 hours, fibres were splashed several periods in purified water. The tensile strength of fibres can be improved, impurities removed, molecular orientation stabilised, fibre surface treated, and the adhesion among hydrophilic AF and hydrophobic PE improved by undergoing alkaline treatment.

2.2. Composite Preparation. Compression moulding was used to create a composite sheet from several AF/PE composites that were created using a manual mixing process. The purpose of high impact polyethylene is to make the products more immune to impact. To ensure that the samples could be easily removed from the mould after pressing, the mould was initially cleansed with wax. The first step in making composite samples is placing the AF and PE mixture in a mould to guarantee that the fibres are oriented in the same direction. In order to create this 3 mm thick sheet, the compound was heated to 190°C for 5 min and 3.5 MPa for 7 min, after preheating at the same temperature. Using a Proxxon saw, the composites were cut into sheets and then cooled for 30 minutes before being tested in accordance with the ASTM standard.

2.3. Analysis of Mechanical Characteristics. An D3039ASTM Standard is used for tensile properties of polymer matrix composite materials. An UTM setup with a constant head speed test speed of 2 minutes per millimetre evaluated the materials with specifications of 140 mm long, 13 mm in width, and 3 mm in depth. The specimen was held in place in the testing machine's grips, and a hydraulic force was applied until it ruptured. The stress–strain curve diagram was used to determine the tensile stress and elongation %. The density of a substance is an assessment about how densely it is packed up. A digital electronic densimeter was used to determine the AF/PE composite's density. Hardness may be described as a measure of the substance's plastic deformation under the impact of external force. An electronic Shore scale "D" type durometer was used to measure the AF/PE composite's hardness in accordance with ASTM D1957, the standard. Using a dial indicator, we were able to determine the samples' hardness by measuring the depth of the indentation. At least 12 mm away from the sample's edge, perform this hardness measurement to avoid biasing the results. Figure 2 reveals the compression moulding setup.

3. Results and Discussion

Figure 3 depicts the tensile characteristics of the AF/PE specimens in the longitudinal path with varied AF loadings. As a standard error bar, each bar in the graph indicates that the obtained number falls within an acceptable range. AF loading has a significant effect on the composites' behaviour. In order to attain a tensile strength of 72 MPa, 65 percent of the AF loading was required. Additions of 25 and 65 percent fibre increased tensile strength by 168 and 354 percentage points, respectively, compared to ordinary polyethylene (PE) and polypropylene (PP), respectively. Compared to other natural composites, the rate of growth is consistent. Research using various cultivars by other scientists has yielded lower tensile strength findings than those achieved here. The composite tested by [6] had tensile strengths of 30–38 MPa in unidirectional orientation AF. The greater tensile strength achieved in this study can be attributed to the characteristics of AF and the effect of alkaline treatment on its surface. In other words, when the AF is parallel to the tensile axis, it is more effective.

Table 1 shows that the maximum tensile strength and strain values were found with an AF loading of 65 wt percent. This is due to the fact that increased fibre loading will increase the composite's strength. Due to the matrix's role in transferring forces to the fibres, a higher fibre loading allows for greater force resistance than a lower fibre content would. It was mixed with a fine powder of polyethylene (PE) (250 micrometres in diameter) during the fabrication of the samples, which resulted in composites. As a result of this, there is a higher degree of fibre-to-matrix attachment. [24] said that strong fibre-matrix adhesion enables stress transfer from the specimen to the fibres, hence increasing the composite's structural characteristics. Due to the increased tensile

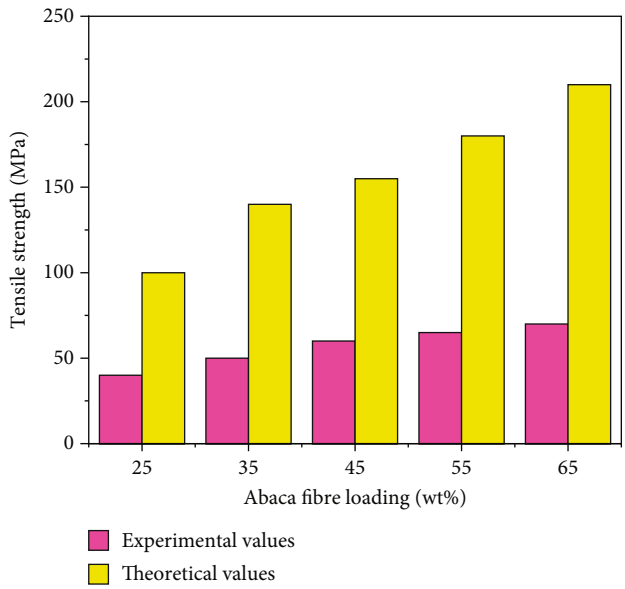

Figure 4: Tensile strength (MPa) vs abaca fibre loading comparison between experimental and theoretical results (wt percent).

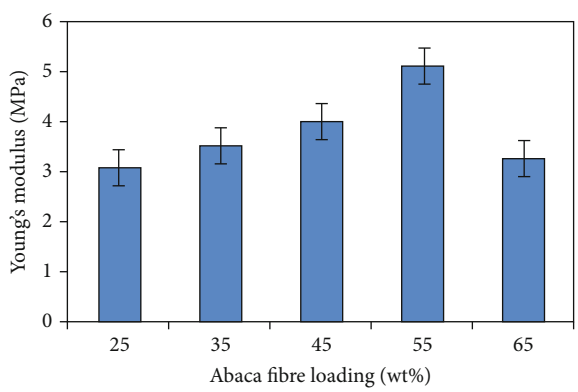

Figure 5: Young's modulus (GPa) vs abaca fibre loading (wt %).

strength brought about by fibre content, the strain characteristics of the material will naturally be reduced. However, the results of this experiment reveal that inclusion of fibre contented enhances strain characteristics, as given in Table 1. More alkaline-treated fibres will therefore boost the composite's strain characteristics, and the AF and PE's high adhesive bonding has evolved because the PE is in precipitate form.

The consequences of the practical and theoretical tensile strength tests were compared using the rule of mixture formula, and the results are shown in Figure 4. The law of combination was utilized to compute the tensile toughness in the longitudinal direction as given in Equation (1). By employing the equation, we were able to determine the volume fraction of fibre relative to matrix (2).

$$\sigma_c = \sigma_m V_m + \sigma_f V_f, \tag{1}$$

$$V_m + V_f = 1, \tag{2}$$

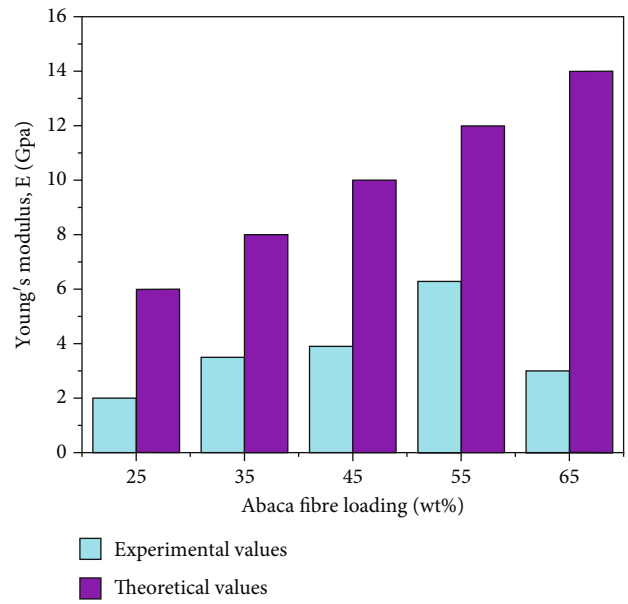

Figure 6: Experimental and theoretical comparison of Young's modulus (GPa) with the loading of the abaca fibre (wt percent).

where σc = composite tensile strength, σm = matrix tensile strength, σf = fibre tensile strength, Vm = proportion of a matrix's volume, and Vf = %volume portion of fibres.

A comparison of actual and theoretical data shows that when AF loading increases, tensile strength increases as well. The experimental results, on the other hand, are lower than expected. Fibres may have been misaligned, and composites may have been improperly produced. Figure 5 depicts the longitudinal Young's modulus of the AF/PE composite under various AF loading conditions. Young's modulus increases with AF loading except at 65 wt percent, as shown in the graph. A 538 percent rise in the Young's modulus of plain PE and a 37 percent decrease in the Young's modulus of 65 percent fibre. The better adhesion between the fibres and the matrix was found to be the cause of the composite's increased Young's modulus.

Figure 6 contrasts the theoretically and experimentally results for the Young's modulus with AF loading. This equation can possibly be used to compute the Young's modulus (3).

$$E_c = E_m V_m + E_f V_f. \tag{3}$$

Figure 7 depicts the Shore-D and density (g/cm3) curves for the longitudinal AF/PE composite based on AF loading. As AF loading is increased, hardness and density both rise. When compared to plain PE, the hardness and density rise by 0.53 percent and 6.93 percent, respectively, when 25 weight percent fibre is added. When AF loading is increased by a factor of up to 65 weight percent, the result is comparable to when the AF loading is increased by a factor of 25 weight percent. Other natural composites are also seeing a rise in popularity. There is a strong correlation between fibre inclusion and composite hardness, according to [28]. The

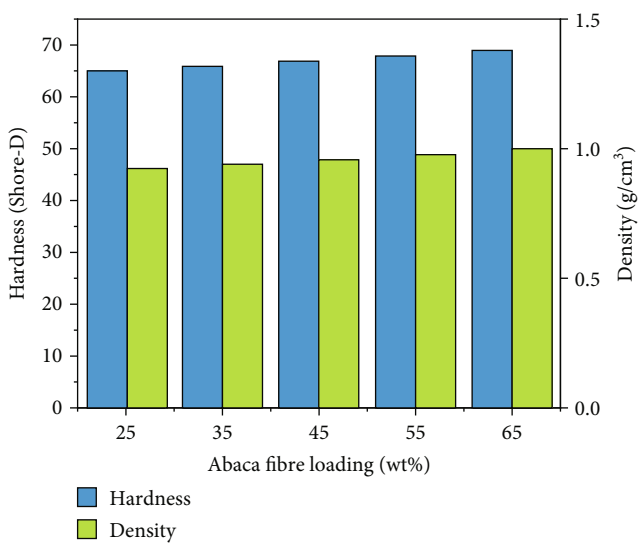

Figure 7: Surface hardness and mass density (g/cm^3) (wt %).

composite's toughness and strength are directly correlated to the material's abrasion resistance. Due to the fibres' tight packing, the composite's density has increased as the content of fibres has raised. Increasing the AF loading in AF/PE composite increased its resistance to indentation, which led to a rise in the composite's density as well.

4. Conclusion

Abaca fibres treated with alkaline have an effect on the mechanical properties of composites and also fibre loading affects the mechanical characteristics of an impact polyethylene composite, and this study has shown to be true. 65/35 AF/PE composites have the best mechanical qualities of the other component ratios (25/75, 35/65, 45/55, and 55/45), with a tensile strength of 69.3 MPa with Young's modulus increases with AF loading except at 65 wt percent and a hardness of 67.52 Shore-D, respectively. Hardness and density both increase as AF loading is increased. As 25 weight percent fibre is added to plain PE, the hardness and density increase by 0.53 percent and 6.93 percent, respectively. When AF loading is raised by up to 65 percent, the effect is equivalent to when AF loading is increased by 25 percent. Uneven fibre distribution has been found to have an effect on the mechanical characteristics of composites made from AF/PE. In order to improve the adhesion between the AF and PE, we intend to add maleic-anhydride-grafted polyethylene or polylactide to dispersion of fibres during the fabrication process.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Mechanical Behaviour and Thermal Properties of Pine Apple Leaf Fiber Reinforced Vinyl Ester Composites

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Despite its mechanical and environmental properties, pineapple leaf fibers (PALF) are used as a home threading material in India. In addition, the effects of abrasive combing and pretreatment techniques on fiber and composite characteristics were examined in this work. Using PALF vascular bundles separated from different regions of the leaves did not affect the mechanical aspects of pineapple leaf fiber-vinyl ester composites. PALF fibers performed equally in strengthening composite flexural properties under static loading, regardless of diameter or location, with a much lower weight percentage and combined pressure. Tests at higher speeds revealed that the PALF-vinyl ester composite was more robust with more delicate bundles. Reinforcing composites that do not require a high degree of hardness can benefit from the cleaner, more delicate bundles produced by abrasive combing.

1. Introduction

For a long time in India, pineapple leaf fibers (PALF) were employed as a home threading material. Agricultural trash as opposed to the PALF used in neighbouring nations to manufacture a variety of products, including garments [1, 2]. In pineapple plantations, leaves are burned or composted, generating smoke and other environmental pollution. PALF are the least investigated natural fibers, despite their environmental friendliness and mechanical superiority, especially when used as reinforcement in polymer composites [3, 4]. Instead of using PALF in textile applications requiring complex processing, polymer composites with PALF reinforcement could still be investigated [3]. Vinyl ester resins are employed in high-performance applications such as corrosion resistant industrial tanks and automotive and marine vehicle components. Pineapple leaf fiber reinforced vinyl ester composites manufactured by fluid compression moulding were found to take good mechanical and other qualities if optimised in a preliminary investigation. As far as we can tell, no other studies have attempted to differentiate and characterise the two forms of pineapple leaf fibers observed in leaf of pineapple, as described by [5]. There were no investigations done on corresponding performance in polymer composites as reinforcement. In spite the occurrence of predominantly vascular bundles, which the researchers calculated to constitute around 75 percent of fiber content in pineapple leaves, previous investigations generally used fine PALF bundles [6, 7]. Most researchers employed PALF with sizes smaller than 100 nm, either stated or inferred from their published work. But the only ones to characterise PALF

that had a diameter of 45-205 m without first separating it into fibrous bundles and vascular bundles employed those that were 50-150 m in diameter [7–11].

Even within the same plant, the size and qualities of natural fibers such as PALF might differ. Qualify whether PALF can be used at random or exclusively from a certain area of the leaves in order to reduce unpredictability [8, 9]. Toxic build up can occur if PALF is stored in a humid Indian climate, where the fibers are more vulnerable to rotting. Because of this, it is beneficial to assess if the PALF reinforcing efficiency decreases over time [10]. The plant leaves are detached from the trunk once the pineapple fruit is harvested. The fibers are then physically scraped away from the leaves; retting or mechanical methods can be used to separate these fibers from the leaves. The cellulose strand bundle is then cleaned and allowed to dry. Physical, mechanical, or chemical extraction of natural fibers like PALF can have a significant impact on fiber costs, yield, and final fiber quality. Due to the inherent inefficiency of automation, PALF are still being manually segregated [11]. Tensile strength of the elementary fibers is only marginally higher than that of the technical fibers due to mechanical processes such as breaking, scotching, and hackling. Abrasive combining of pineapple leaf fiber vascular bundles was attempted by [12, 13] due to the difficulty in obtaining fiber defibrillation. In tests on single fiber tensile integrity, this simple approach generated bundles with a 50.3 percent reduced mean diameter ($p = 0.01$) than expected with little impact on fiber integrity. For the purpose of this work, the properties of vinyl ester composites reinforced with abrasive-combed pineapple leaf fibers were examined and contrasted against properties of vinyl ester components reinforced with rough bundles and fine fiber strands [14]. The mechanical characteristics, hydrophillicity, and fiber-matrix adhesion of natural fibers have all been improved by the use of various treatments and modifications, including PALF. All of the treatments examined by [15] employed a 0.5 percent solution of sodium hypochlorite (NaOCl) for 60 minutes of water bleaching. To get a desirable natural fiber fabric with little strength loss, a simple treatment using NaOH and sodium hydroxide was employed. If the pretreatment has any influence on PALF or PALF/vinyl ester composites, it must be studied [16]. Tests on untreated, pretreated, and abrasive-combed pineapple leaf fibers were conducted in this research. Study of the flexural and impact properties of this vinyl ester composite was carried out [17]. We learned more about PALF and how they could be employed as reinforcement in vinyl ester composites as a consequence of our research.

2. Experimental Procedure

2.1. Materials. Pineapple leaf fiber is a stiff, light-weight material that is used for formal wear, as well as a heavier-duty material that is utilised as a leather substitute in fashion and footwear. PALF also has the advantages of being low density, low cost, biodegradable, and renewable. Pineapple leaf fiber vascular bundles and fibers of six months of age were used in this study. In order to simulate the combing and separation process, huge vascular bundles were pulled between #100 sandpapers, resulting in abrasive-combed PALF. The most common usage of NaOCl, generally known as bleach, is as a disinfectant. It is a broad-spectrum disinfectant that may also be used to disinfect substances. NaOCl aqueous solution was utilised for 1, 2, and 4 hours to clean the fibers. One group of fiber specimens was soaked in water for 24 hours. For a few rinses, we used tap water and then distilled water to clean the fiber samples. When vascular bundles were combed, leaf tissue was taken for thermogravimetric examination. The majority of the PALF names and descriptions may be found in Figure 1.

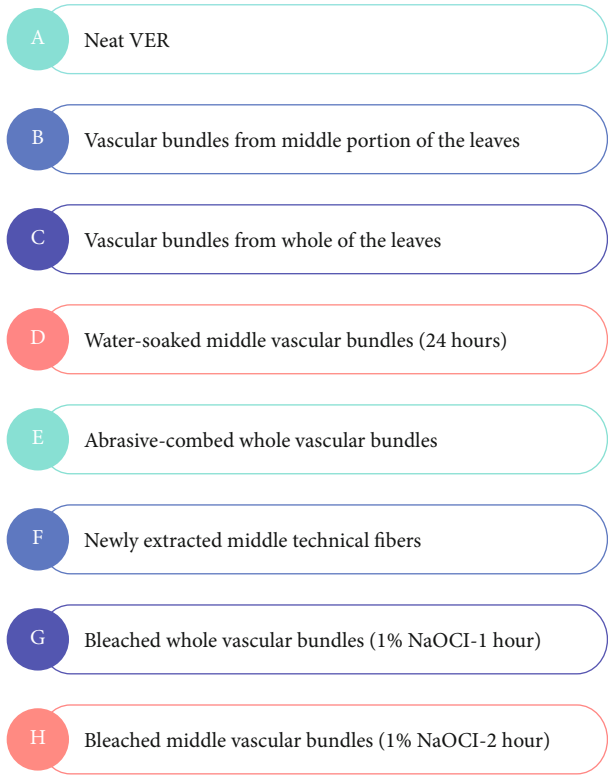

Figure 1: Pineapple leaf fiber sample designations and descriptions.

2.2. Specimen Preparation. To make the mould, three pieces of aluminium were used to create a hollow, and the pineapple leaf fiber bundles were sliced into 127 mm lengths. PALF was utilised in all samples at a concentration of 20 wt percent because higher concentrations would necessitate the use of pressure and a distinct mould. Newly extracted pineapple leaf fiber fine fiber strands were employed to reinforce composites in one set of specimens. The cover was lightly pressed to ensure that the sample dimensions remained constant. A minimum of 72 hours was required for all samples to cure at room temperature. For comparison, vinyl ester resin specimens were also made.

2.3. Thermo Gravimetric (TG) Analysis. Thermo gravimetric analyzer tracks changes in mass and weight as a function of temperature and time. These measures can reveal a lot about

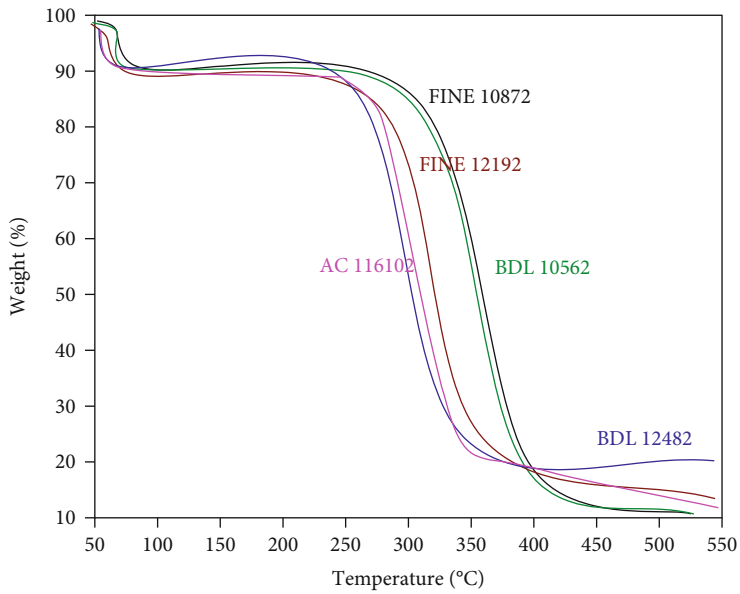

Figure 2: A comparison of nontreated and bleached PALF using thermal gradient analysis (TGA).

a material's thermal stability, oxidation resistance, composition, breakdown kinetics, and moisture content. A Perkin Elmer Diamond TG/DTA analyzer was used to measure the thermophysical characteristics of several fiber samples. Specimens were heated at a rate of 10°C/min in a nitrogen flow of 80 ml/min and scanned from 30 to 580°C.

2.4. Tests on Bending and Impact. Flexural testing establishes a material's resistance to flexing by measuring the force necessary to bend a beam of plastic material. Impact test determines engineering materials' toughness, strength, and notch sensitivity. The composite sheet flexural properties were examined with 5 kN load cell with sample measuring 63 mm in length, 12.8 mm in width, and 3 mm in thickness, using ASTM D790 standard. A crosshead speed of 2 mm/min and a span to thickness ratio of 16 were used. In order to conduct unnotched Charpy impact tests on 64 mm long, 13.2 mm wide, and 3 mm thick specimens, the impact tester and the ASTM D256 were employed. There were five specimens tested in each of the following assays; mean and standard deviation were given.

3. Results and Discussion

The thermal stabilities of untreated PALF vascular bundles and fine fiber strands were the same, indicating their similarity. After pretreating pineapple leaf fiber with aqueous sodium hypochlorite solution, pineapple leaf fiber thermal stability was reduced due to fiber degradation, as seen by decreased crystallinity indexes. Between 100 and 200°C, the PALF loses more weight due to the higher moisture absorption that occurs as a result of bleaching. When the curves were shifted by the average values of weight loss in the 100 to 200°Celsius range, there were no variations in weight loss between 100 and 200°Celsius, and it is shown in Figure 2. There was an increase in the amount of char products because the PALF was pretreated with NaOCl solution. Although NaOCl was formerly assumed to delignify PALF fibers, this was not the case.

Table 1: Crystallinity indexes of various PALF.

Types of pineapple leaf fiber	Crystallinity index
Soaked for 24 hours in water-	74.26
Abrasive-combed	73.12
Fine fiber strands	74.42
1% sodium hypochlorite (2 hours)	73.14
1% sodium hypochlorite (4 hours)	71.28

There are less epidermal tissues in fine and abrasive-comb PALF as a result of this contrast, and this is evident in products of former cases. Abrasive combing assisted in the separation of pineapple leaf fiber bundles and eliminated further epidermal tissues in the fiber surface. [18] found no difference in the crystallinity index between jute that had not been treated and jute that had been treated for 24 hours with up to 0.08 percent NaOH. Only bleached PALF showed a decrease in crystallinity during the pretreatment period. Various crystallinity indexes of various PALF are shown in Table 1. Due to increased fiber crystallinity, natural fiber tensile modulus and strength have decreased over the past few decades; this can be explained by this trend.

$$I_{\mathrm{XRD}} = \frac{I_{200} - I_{am}}{I_{200}} \times 100. \quad (1)$$

Vinyl ester flexural strength of 20% untreated PALF substantially enhanced contrasted to Korte who observed a significant loss with comparable weight fractions of preserved fibers in epoxy. Based on the mechanical properties of

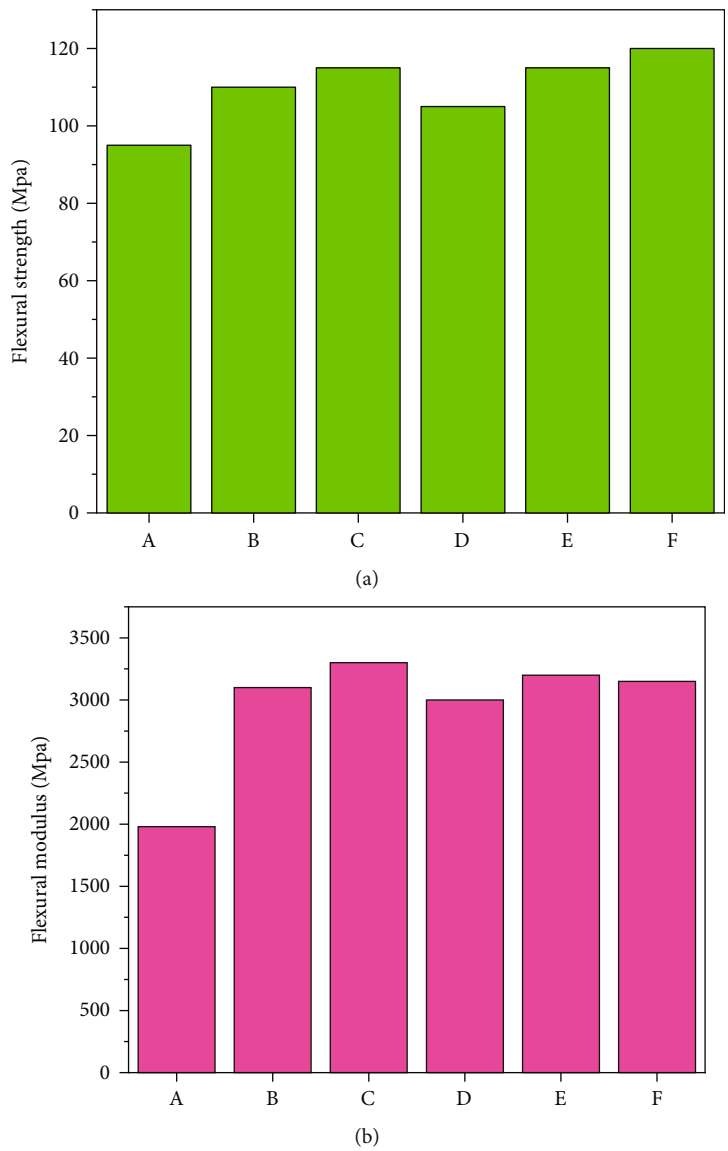

Figure 3: (a) Flexural strength and (b) modulus of neat vinyl ester reinforcement and pineapple leaf fibers reinforced vinyl ester composites.

composites, fiber reinforcing capacity in composites was equivalent to that seen in published data at the same fiber fractions. Due to incorrect fiber matrix bonding, the PALF fiber strength and modulus were larger or close to those published in the literature, despite lower mean values compared to those produced in single fiber testing, and it is shown in Figures 3(a) and 3(b).

The composite's bending stiffness was greatly improved ($p = 0.01$) after the addition of PALF. Stubbornness was unaffected by the addition of PALF sourced from various parts of the leaves, as was strength. Fiber diameter did not appear to affect the stiffness of composites in a significant way. When [19] employed PALF that were much finer, the bending was remarkably similar. Low fiber weight and high consolidation pressure proved to be ideal conditions for PALF vascular bundle and fine fiber strand reinforcement in vinyl ester composites. In pineapple leaf fiber vinyl ester composites, untreated pineapple leaf fiber from varied leaf positions had no significant effect on the flexural properties.

Figure 4 shows that soaking pineapple leaf fibers in water for 24 hours had no effect on the composite's flexural strength or modulus (a, b). In order to save time and money, the emphasis should be on thoroughly washing away soil and grime using plenty of water, rather than soaking for long periods. The loss in fiber strength and ductility caused by treating PALF in aqueous NaOCl solution lowered the composite's strength. At high quantities or over a lengthy period of time, sodium hypochlorite bleach has been known to produce chain and the subsequent deterioration of textiles. When PALF is bleached, it loses its ability to bend; hence, the stiffness of the composite increases significantly (H).

The idea of "normalised fiber strength" is discovered to the decisive element in composite flexural strength for fibers with same sizes, such as vascular bundles, and its effect is

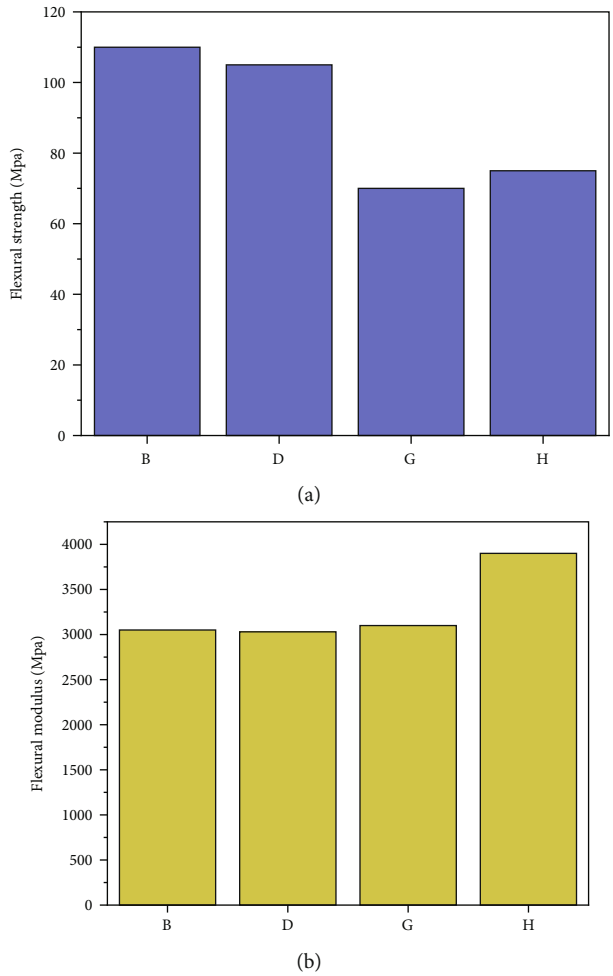

Figure 4: (a) Flexural strength and (b) modulus of neat vinyl ester reinforcement and pineapple leaf fiber-vinyl ester reinforcement composites.

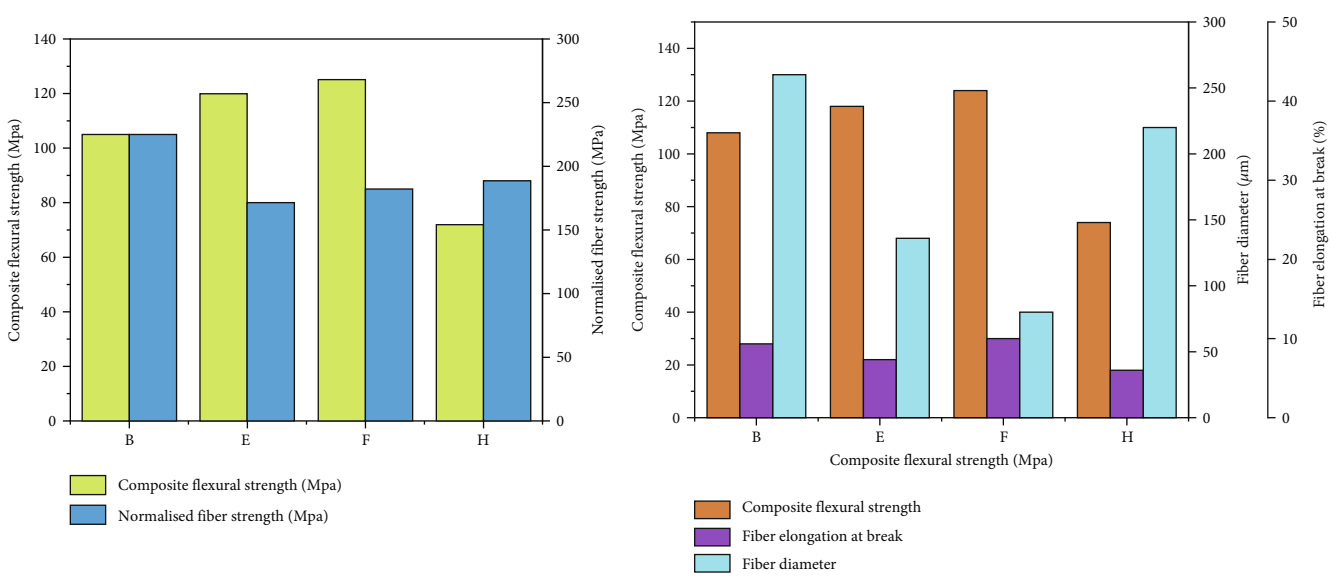

Figure 5: The effect of normalised fiber strength, fiber elongation at break, and fiber diameter on composite flexural strength.

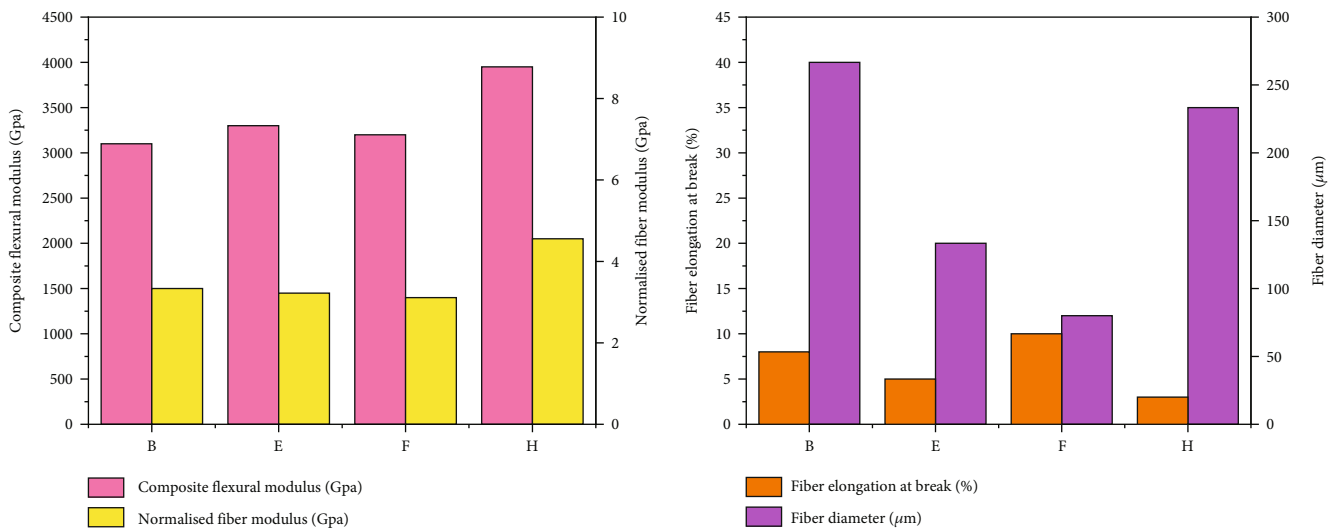

Figure 6: The impact on the composite flexural modulus, normalised fiber modulus, fiber elongation at break, and fiber diameter.

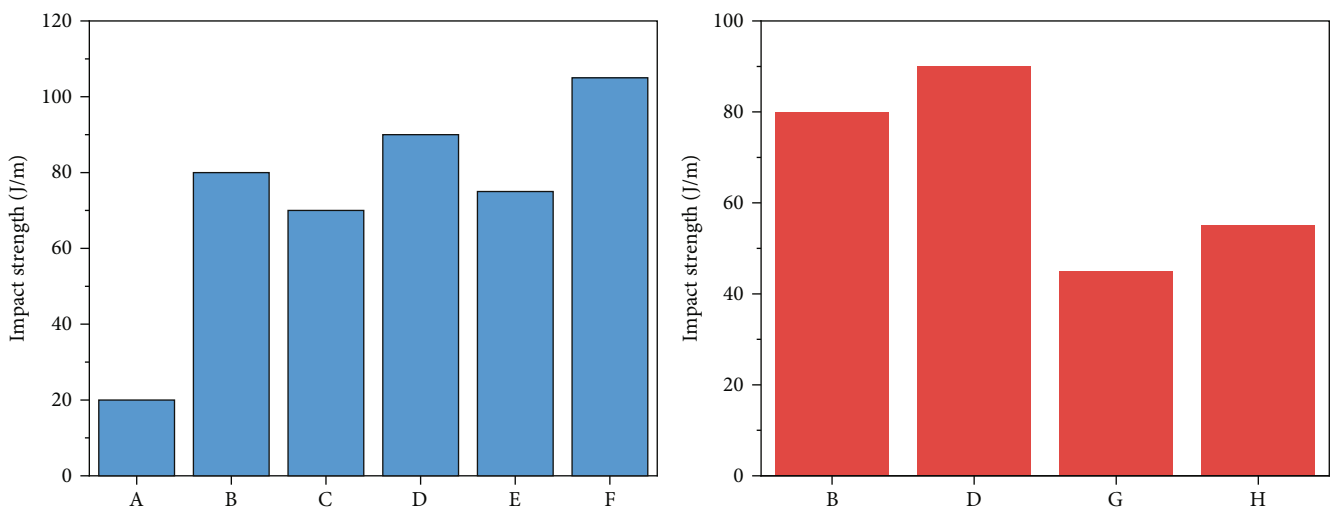

Figure 7: Impact strengths of VER composites with untreated pineapple leaf fibers and VER composites with treated pineapple leaf fibers.

shown in Figure 5. For flexural strength, finer fibers resulted in developed fiber-matrix interfacial shear stress and hence a higher level of interfacial shear stress. Composite flexural modulus has the same problem, and it is shown in Figure 6. With a mean value nearly equivalent to 35% washed pineapple leaf fibers reinforced composites adding 20 weight percent of untreated pineapple leaf fibers to vinyl ester boosted impact strength by 4 times, and it is shown in Figure 7.

Pineapple leaf fibers can be blended and used at random, as demonstrated by using vascular bundles from various regions of a leaf, which did not pointedly influence the impact strength of composites. We found pineapple leaf fiber strands directed to improved composite durability than vascular bundles (V), which means that PALF fiber diameter plays a significant role in decisive the impact strength of pineapple leaf fibers reinforced vinyl ester composites at less fiber weight portion overlarge number of fiber-matrix interactions, as demonstrated by the results of this study, and it is shown in Figure 8. Increasing the number of fiber matrix interfaces is expected to improve performance, as will increasing fiber weight fractions and consolidating pressures.

There were no apparent negative effects on the flexural properties of vinyl ester-reinforced pineapple leaf fiber composites (E) when fine fibers (F) were used in place of the fine abrasion-combed PALF bundles (E), although their use reduced the composite toughness. Because abrasive combing introduces flaws on the fibers, this behaviour could be explained by faults that is not detected through low speed fiber and composite flexural tests, which are common in the industry. According to the findings of this study, testing at higher speeds can detect poor fiber integrity, so it is necessary to compare the mechanical properties of fibers at both

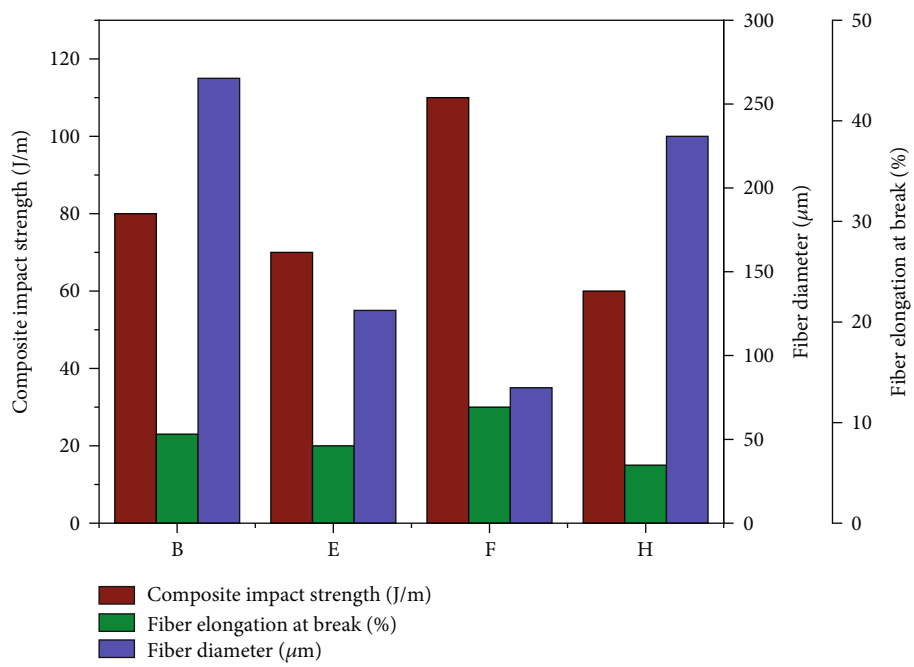

Figure 8: Fiber elongation at break and fiber diameter have an impact on composite impact strength.

low and high speeds. Higher fiber fraction and higher consolidating pressure should alleviate or even eliminate this flaw.

The extremely brittle fibers in bleached PALF (*H*) reinforced composites greatly lowered their toughness. A longer pretreatment duration did not diminish the toughness any more, which may be due to the lacking of additional degradation in pineapple leaf fibers. The PALF strength-treatment data and the substantial drop in PALF elongation at breaks can be seen as a result of this phenomena. The impact of abrasive combing on pineapple leaf fiber performance in pineapple leaf fiber vinyl ester composites requires additional research. This basic extraction process, however, appears to create finer PALF bundles of acceptable quality, as shown by the aforementioned data.

4. Conclusion

According to the findings of this investigation,

(i) PALF's reinforcing potential has not been compromised by prolonged storage in hot, humid environments. Some epidermal tissues on the fibers and PALF's position in the leaves did not affect the composite's flexural and impact capabilities

(ii) To improve the mechanical and thermal properties of PALF and promote the adherence of PALF to vinyl ester, extended soaking and pretreatment with diluted household NaOCl solution are ineffective

(iii) The flexural characteristics of pineapple leaf fiber reinforced vinyl ester composites can be improved by increasing the PALF volume fraction, although fiber width has minimal influence

(iv) The diameter of the PALF has a significant impact on the toughness of a pineapple leaf fiber reinforced vinyl ester composite. Cleaner and more delicate bundles are produced by abrasive combing in PALF extraction, suitable for supporting composites that do not require a lot of toughness

(v) Another finding of this research was the potential of PALF reinforced vinyl ester composites for producing interior car and home application quality products

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Investigation on Mechanical Properties of Bamboo and Coconut Fiber with Epoxy Hybrid Polymer Composite

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The present study focused to improve material characteristics and quality in terms of the NaOH concentration for treating the coconut and bamboo fiber to enhance the mechanical properties of natural fiber polymer-based hybrid composites. The NaOH-treated fibers were washed thoroughly using distilled water and allowed to dry for 24 hours. Composition of each specimen, bamboo (B) and coconut (C) fiber with epoxy composite, was prepared by hand layup process as per the American Society for Testing and Materials (ASTM) standard. The proportionality of the material was carefully fulfilled according to the previous literature reports. The weight fraction of the composite material content was set to be 30% and 70% of epoxy (E) resin and isolated fibers. Three distinct criteria were used to calculate mechanical parameters such as tensile strength, flexural strength, and material hardness. It was found that the combination of 70% E with 30% BC of hybridized composite had a maximum tensile strength of 62.42 MPa, whereas the flexural strength and hardness of the other combinations, such as 70% E with 30% C and 70% E with 30% B, were observed to be 58 MPa and 185 HRC (Hardness Rockwell C), respectively.

1. Introduction

The past few decade materials accrued from the surrounding nature such as wood, sticks, bricks, stones, animal skins, and bones. However, the people are fascinated to weave natural fibres to make cloths with composed materials which are silk and cotton. Highly, the synthetic materials from plastics can be organic and inorganic category or natural fiber or synthetic material. The researches encountered the need of the customer represented as synthetic organic plastics and essentially termed as polymers. Some other elements contained nitrogen, oxygen, silicon, chlorine, etc. In general, polymers are regulated by the process of polymerization, and monomers are bonded in line chain mode. Composite

material is defined as a mixture of matrix and reinforcement to make superior properties of the components. Based on the material dimension, alignment and angle position which will affect the properties of material [1]. The past decade composite materials were dominated as emerging materials such as plastics, mica, and ceramics. However, in order to establish applications of composite materials, the market focused on cost, availability, and safety. As a result, the market has steadily grown and penetrating acquired materials. Recently, several innovative techniques were done in composite industries and overcome certain cost hurdles. Accordingly, different essential things should be followed up with respect to designing, tooling, quality control/assurance, material process, etc. [2]. Fiber-reinforced polymer offered cost-effectiveness to overcome the market dream, and certain applications may cover both cost and weight such as cascades for engines, replacements for welded metallic parts, cylinder, and ducts. Usage of composite is increased day by day, and adoption increased throughout the industry, and composites are lightweight, more stiffness, more strength, etc., and additionally, their corrosion and chemical resistant in nature functions with increasing the service life during the cycle and all-natural composite structure using many applications and materials used based on resin soybean oil and natural fibers such as flax, recycled paper, and cellulose. Then, the researcher team focused on the next gen of biocomposites with the example of fiber-reinforced composite with the combination of matrix and reinforcement from natural and renewable resolution termed as hybrid composite. Recently, the bamboo can be significantly used because of its easy availability. It has appreciable mechanical characteristics. It can be recyclable. In addition, wastes from bamboo can be effectively utilized in the form of fibers, ash, and particulates. Different studies have reported that the bamboo fibers can be accompanied effectively for the corresponding increase of the mechanical properties of the composites. As reported elsewhere, biodegradability and thermal stability the of matrix can be significantly improved with the addition of bamboo fiber. Similarly, the coconut fiber is known as a nonedible, which is widely considered as waste material and usually dumped in landfills. Also, this possesses good strength and modulus. Previous researches have shown that coconut fiber has the ability to improve the compressive strength when incorporated into epoxy matrix. The tremendous factors were considered to invent new manufacturing lightweight composites [3]. Figure 1 displays the methods and stages of fabrication. In the present study, the NaOH concentration for treating the coconut and bamboo fiber to enhance the mechanical properties of natural fiber polymer-based hybrid composites was investigated.

2. Literature Review

Based on the previous experimental results, the highest mechanical properties, with tensile strength of 39.16 MPa and flexural strength of 61.10 MPa measurement (date palm hybrid composites), can be achieved by nonhybridization. The properties of bamboo/palm hybrid polymer composites varied depending on hybridization or nonhybridization.

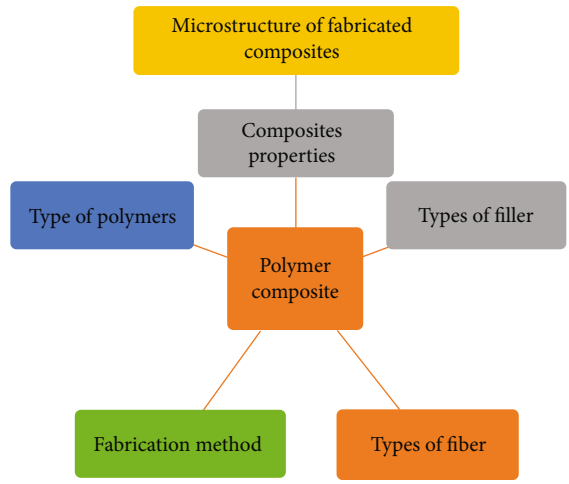

Figure 1: Methods and stages of fabrication.

Water absorption treatment has shown a significant result of the reduction of hydrophilic characteristics followed by the material treatment to agglomerate the particle and achieve excellent adhesion between the materials [4]. The effect of fiber loading on the performance of sisal and bamboo epoxy resins. They used NaOH to remove the hydrophilic characteristics of the hybrid composite hydroxyl groups in hemicellulose, cellulose, and lignin. As a result, the material had achieved high adhesion between fiber and matrix [5]. Alkaline treatment reduces the mechanical strength of bamboo. The contact between untreated bamboo and epoxy resin is poor. If the tensile strength and Young's modulus of the bamboo fiber fall, the adhesion between bamboo fiber and epoxy resin could be enhanced by alkali treatment [6]. Unidirectional fiber pattern, different overlapping length of adjacent fiber bundle, and randomized of individual fiber end. Tensile stiffness is unaffected by discontinuity pattern, but inserted randomized fiber and discontinuity resulted in a loss of 85% longitudinal tensile strength in comparison to unidirectional bamboo fiber composite [7]. Six distinct random oriented fiber-reinforced polyester composite samples were created. Tensile strength and Young's modulus both reduced coir fiber inclusion, however, increasing the stiffness and ductility of coir fiber composites [8]. Effect of bamboo fiber-reinforced epoxy and rice husk filler loading on modulus of elasticity, flexural strength, and impact strength was evaluated. 15% filler loading resulted in higher modulus of elasticity, flexural strength, and impact strength. The modulus of elasticity increases linearly with filler loading [9]. When coconut coir fiber was combined with epoxy, it resulted in a plastic material with corresponding tensile strength, input strength, and hardness strength. The hardness of the material increases as the weight percentage of the coir fiber increases. The maximum tensile strength of bamboo fiber was 84.61 MPa [10, 11].

3. Experimental Work

3.1. Specimen Preparation. The experimental work was designed and constructed in accordance with the American

Figure 2: Bamboo and coconut shell powder.

Table 1: Properties of coconut fiber and bamboo fiber.

Properties	Coconut fiber	Bamboo fiber
Density	1.288 g/cm^3	0.9 g/cm^3
pH	11.6	6
Moisture content	10% max.	14.01%
Sp. gravity	1.33	0.68
Water absorption	23%	26.2%

Table 2: Properties of epoxy resin.

Properties	Values
Grade	LY556
Color	Pale yellow
Sp. gravity	1.10-1.20
Epoxy content	5.0-5.9 Eq/kg
Volatile content	0.75%

Table 3: Material composition.

Samples	Bamboo fiber	Coconut fiber	Epoxy	Treatment
Bamboo (B)/epoxy (E)	30	—	70	
Coconut (C)/epoxy	—	30	70	NaOH
Bamboo/coconut/ epoxy	15	15	70	

Society for Testing and Materials (ASTM) standard plate dimensions of 300 ∗ 250 ∗ 10 mm. First stage of work is mixing resin and hardener with tabulated/calculated proportion and assured by weight measuring equipment. All the components are completely reacted on the specific container. Figure 2 shows the bamboo and coconut shell powder, and Table 1 shows the properties of coconut fiber and bamboo fiber which were determined as per the standard procedure. Epoxy resins (polyepoxides) are a class of reactive polymers which usually contain epoxide groups. In the present study, the epoxy resin (LY-556) was used as matrix

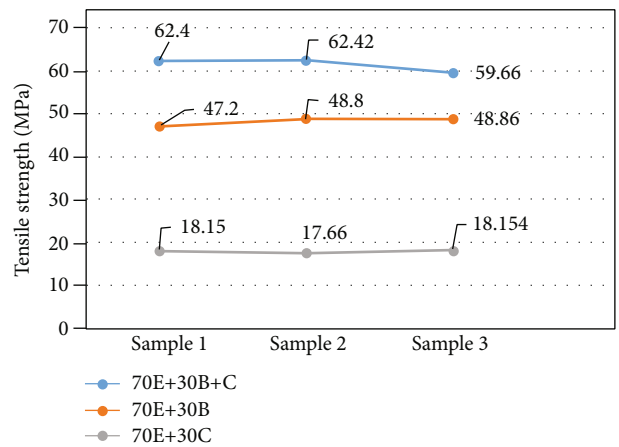

Figure 3: Samples testing for tensile strength.

binder which was supplied by StarChem, India Ltd. Epoxy resin and hardener mixing thoroughly with the proportions of 10 : 1. Table 2 shows the properties of epoxy resin that were obtained from the experimental procedure. Primary polymer content is distributed uniformly over the plate and rolled up. Secondary layer fiber content was placed over the surface and matted up uniformly by process of rolling. Excess air was evacuated and contained by the rolling tool while under brief pressure. The final stage of the process ensures the ASTM dimensions with agreement to close the mould by wooden plate or steel plate with uniformly applied specific load. It has been considered for curing the epoxy after loading. All of the specimens were constructed to provide ASTM standard dimensions and are sliced to perform various tests to evaluate the composite. Table 3 displays the material composition in which the samples were made.

4. Result and Discussions

Mechanical testing is performed on three separate samples (70E + 30B, 70E + 30C, and 70E + 30BC) (tensile, hardness, and flexural testing). The testing ranges may vary depending on the amount of samples. Figures 3–5 show the average values for each testing result. Figure 3 shows that 70E + 30 BC had a maximum tensile strength of 62.42 MPa, which remained constant for samples 1 and 2. Similarly, Figures 4 and 5 show the maximum hardness and flexural strength for which the sample was suitable. For samples 2 and 3, 70 E + 30B obtained the ideal range and sustained 185 HRC, while 70E + 30C obtained the consistent range. For samples 1 and 3, the best range and sustained average value for flexural strength was 70E + 30C.

Figure 6 depicts a graphical representation of varying fiber contents versus tensile strength variation for three different combinations of changed surfaced material. The true measured tensile strength was increased by increasing the ranges up to 62.42 MPa. Tensile strength significantly decreases in the order of 48.8 MPa and 18.15 MPa for bamboo epoxy and coconut epoxy alone. The descent of the tensile strength gradually slant in the order of 48.8 MPa and 18.15 MPa for bamboo epoxy and coconut epoxy alone.

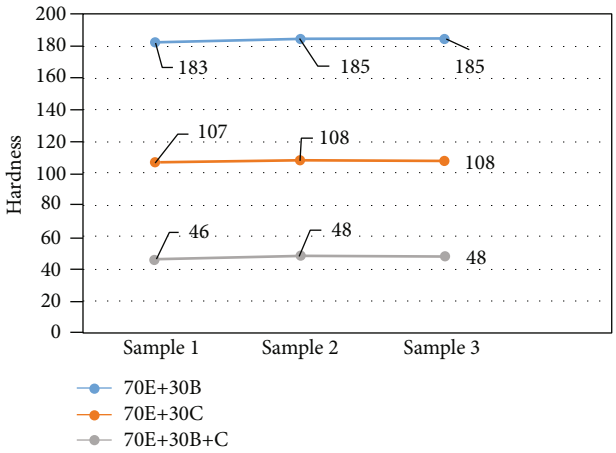

Figure 4: Samples testing for hardness (HRC).

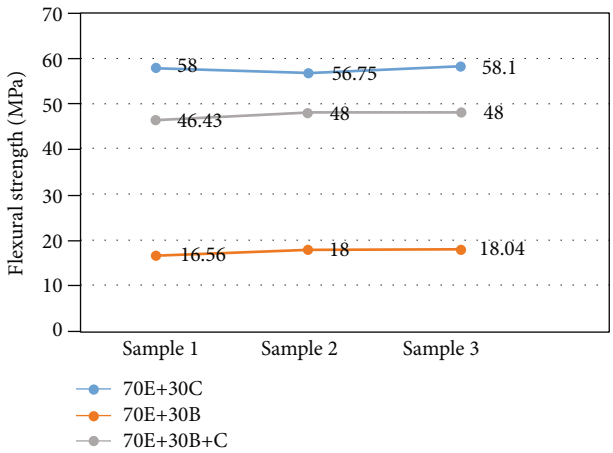

Figure 5: Samples testing for flexural testing.

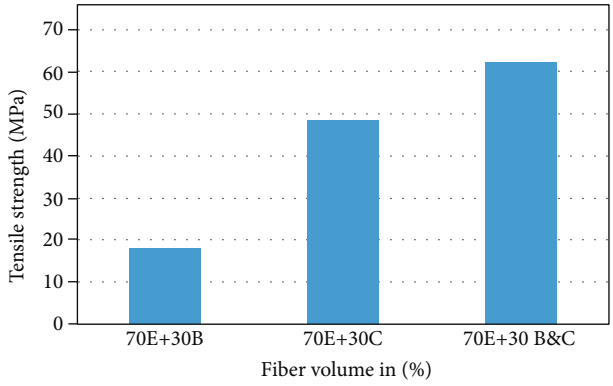

Figure 6: Tensile strength with different fiber contents.

The addition of NaOH treatment for both bamboo and coconut fiber isolated and combined material marginally were increased correspondingly. After alkali treatment, the fiber was derived from the sun light reaction for 24 hours, and a finer fiber with excellent solid crystal was generated. During the material composition and epoxy combination

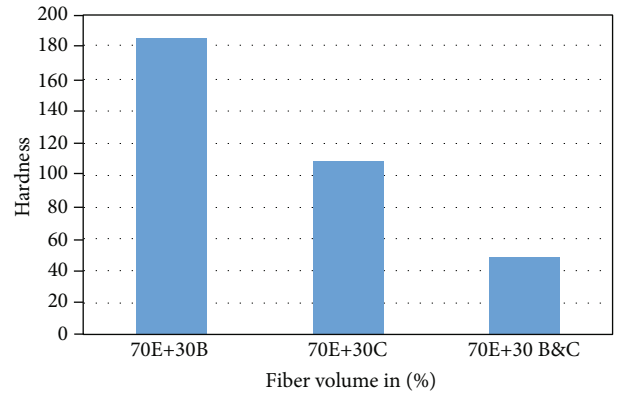

Figure 7: Hardness vs. fiber volume in %.

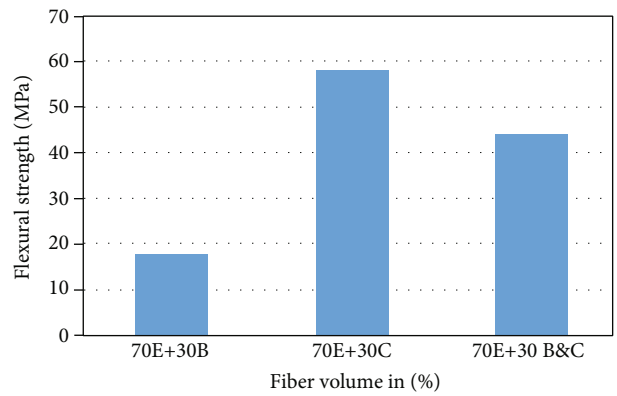

Figure 8: Flexural strength for various fiber contents.

were perfectly adhered with the material inspected by the testing result, the rate of tensile strength had reached 62.42 MPa for the recognized designation of the material 70E + 30BC.

Figure 7 indicates the hardness range 185 HRC at 70E + 30B. This reversal character was improved as a result of material dispersion, and surface modification treatment is a significant factor. A single-dried material is arranged uniformly, and fiber contents were distributed along the plate dimension. Once epoxy was coated over surface and after loading the material, perfect interaction between the materials has been formed. Interlocking the material and bonding structure to a greater level resulted in hardness tests at a maximum of 185 HRC and corresponding 70E + 30C and 70E + 30BC observed at 108 and 48 HRC, respectively.

Figure 8 represents 70E + 30C composite with a maximum flexural strength of 58 MPa. The important factor is considered to reach the maximum value for loading fiber content of materials of 30% for all the fibers bamboo and coconut; additionally, surface treatment had been done to improve the material properties for the superiority level. Certain parameters were reached by the isolated combination of the ingredients (hardness and flexural strength). However, the hybrid combination 70E + 30BC achieved the majority of the expected features.

5. Conclusion

The present study is aimed at improvising the mechanical properties of coconut and bamboo fiber. Accordingly, in order to attain the best mechanical qualities, three alternative fiber loadings were examined. It was found that the material configuration comprised flawless orientation of the fiber was retained after the surface treatment followed by sun light exposure that was made ideal crystal structure forms. From the studies, the experimental results of the bamboo and coconut epoxy hybrid composites demonstrated the highest mechanical performance compared to bamboo and coconut composites without hybridization. Significantly, the maximum tensile strength of the 70E + 30BC hybrid composite was observed to be 62.42 MPa. Likewise, the 70E + 30B and 70E + 30C combinations achieved maximum hardness and flexural strength of 185 HRC and 58 MPa, respectively.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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Research Article

Date Palm Fiber-Reinforced Recycled Polymer Composites: Synthesis and Characterization

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In this research study, Recycled Polymer (RP) composites are synthesized by using compression molding process, initial mixtures of RP and Date Palm Fibers (DPF) with four different lengths (e.g., 2.5, 5, 7.5, and 10 mm) and weight ratios (e.g., 5, 10, 15, and 20 wt%). The RP composites utilized in this study are polyethylene and polypropylene. The mixtures of RP and DPF are heated at 80°C and then poured into a priori prepared mold. The mold is designed to have three cavities for three specimens in order to characterize them through impact, creep, and tensile tests. The results showed that the hardness and impact increased with this process. In addition, an increase in the DPF up to 15 wt% was observed with a small increase in the DPF length. High creep resistance was also observed to be 10 mm with 20 wt% in the DPF specimens. The maximum strain was obtained in a 2.5 mm fiber length with 5% of DPF due to ductility of the plastic matrix. Moreover, with a small ratio of tough DPF, short fibers are unable to block or resist rapid plastic deformation in specimens. In fact, the DPF specimens of 10 mm length with 20 wt% exhibit a high tensile strength of 78 N/mm^2 in comparison with other composite specimens. This is due to the length and content of fibers, which improve transferring action and microfailure modes.

1. Introduction

Thermoplastic material has replaced most of the metals used in many applications. Commercial consumption of plastic has become noticeable in the past centuries, despite of the increase in its price. Therefore, reinforced plastic material was developed to reduce prices and increase efficiency [1]. To replace metals with thermoplastics, their properties must be improved to be the perfect competitor to metals, as most metal-based applications require high hardness and high impact strength. Stronger plastic composites (e.g., natural fibers and polymer) can offer considerable advantages because they (1) are low cost materials, (2) are available, (3) can be easily manufactured, (4) have low density per unit volume, (5) have high strength, and (6) are not toxic and not harmful to the skin and eyes [2]. Moreover, mixing natural fibers with petrochemical polymers increase the degradability of composites. This type of polymer is a source of environmental pollution, and it is harmful to wildlife when spread in the environment. Globally, approximately 40 million tons of single-use plastic packaging are used annually [3]. Recently, the interest in recycling plastic has been increased in order to reduce environmental pollution and energy consumption in addition to using the resources appropriately. In fact, recycling contributes effectively in the reduction of production costs.

The shape of fibers is typically cylindrical with a diameter of 100-1000 μm. The main components of fibers are cellulose, hemicellulose, and lignin where hemicelluloses and lignin are considered to be the support material in cellulose microfibers. Composites reinforced with natural fibers are among the most promising advanced materials because of their similar properties with some metals, which are used in most modern engineering structures [4]. Fiber-reinforced composites include parts made for airframes, cars, spacecraft, ships, many sports equipment, and infrastructure [5]. The use of synthetic fibers, produced from petroleum, has been decreasing due to the continuing tendency to introduce natural fibers in modern engineering applications. Natural fibers are found in animals and plants

Table 1: Research studies on thermoplastic-based RP-DPF composites.

Reference	Fabrication method	Type and rations of fibers	Matrix materials	Mechanical tests
Alawar et al. [16]	Double screw extruder	Untreated date palm tree fibers with rations of 25 wt%.	Polypropylene	Tensile strength and modulus of elasticity
Sadik et al. [17]	Hand layup	Date palm frond fibers with rations of 30, 40, and 50 wt%.	Polyethylene	Tensile strength, bending strength, impact strength, and hardness
Mahdavi et al. [18]	Extruder, hand lumpy shapes, and hot press	Trunk, rachis, and petiole with rations of 20, 30, and 40 wt%.	Polyethylene	Tensile strength, and flexural strengths
Alewo et al. [19]	Casting poured into the prepared mold prepared samples were then cut according to ASTM	Date palm seed particle with rations of 5, 10, 15, 20, and 25 wt%.	Polyester	Tensile strength, elastic modulus, and hardness
Al-Otaibi et al. [20]	A twin-screw extruder and injection molding machine	Date palm fiber with rations of 5, 10, and 15 wt %	Recycled homopolymer polypropylene	Tensile strength and tensile modulus
Alsewailem et al. [21]	The blends were melt mixed for 10 min and then injected into a mold	Date pits with rations of 30 wt%	High density polyethylene (HDPE) and polystyrene (PS)	Tensile and impact
Lei et al. [22]	Composites with dimensions of $350 \times 350 \times 5\ mm^3$ were obtained using thermocompression. Thermocompression was performed in a hydraulic press	Wood and bagasse with rations of 30, 40, and 50 wt%	Recycled high density polyethylene (RHDPE)	The modulus and impact strength
Dehghani et al. [23]	Composites were prepared using twin-screw extruder followed by injection molding	Surface treated date palm leaf fiber with rations of 5, 10, and 15 wt%	Recycled poly (ethylene terephthalate)	Tensile strength, flexural strength, and impact strength
M.d. K. Hossain et al. [24]	Composites were prepared using 8 inch × 6.5 inch rectangular closed steel mold of 450KN Weber-press together with the HDPE pellets. The mold was then compressed with 100KN pressure at 145°C for 20 min and allowed to cool to room temperature	Jute-mat fiber with rations of 25 wt %	Density polyethylene (HDPE)	Tensile strength, young modulus, flexural strength, tangent modulus, and hardness
Masri et al. [25]	The reinforcement is mixed with the matrix and lignin. Then, the mixture (reinforcement/matrix/lignin) is poured into a metal mold to obtain plates of dimensions $240 \times 120 \times 10\ mm^3$; a holding pressure of 3.5 bar is applied for 10 min to ensure a good distribution of the mixture and to reduce the air in the LPC	Leaflet with rations of 70%	Recycled polystyrene	Three-point bending tests and elastic modulus

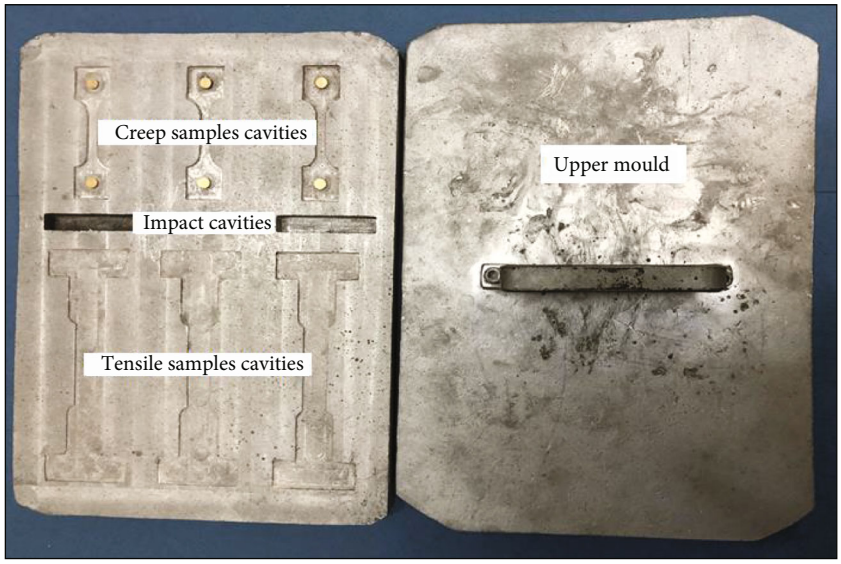


Figure 1: Iron compression mold after machining and polishing.

[6]. They provide the perfect alternative to expensive and environmentally harmful synthetic fibers [7]. In addition, they have high moisture absorption and low compatibility with the matrix. To remedy these shortcomings, the surface properties of fibers must be improved [8].

Many researchers have conducted their studies on the properties of thermosetting polymers with DPF composites [9–15]. However, in this research study, the mechanical properties of the thermoplastic-based RP-DPF composites have been enhanced by using natural fibers, recycled polyethylene and polypropylene, and steel mold in addition to using different fabrication method, matrix materials, fiber types, and weight ratios in comparison with the testing settings shown in Table 1 [16–25]. Note that the proposed fabrication method is performed with a lower cost in comparison with the methods introduced in the literature due to using recycled polyethylene and polypropylene polymers. In this study, the fabrication method involves softening, adding a reinforcement, mixing, and pouring the mixture into the mold. In fact, the results demonstrated in this study have been obtained by synthesizing recycled plastics with natural fiber composites using cheap and abundant material with good properties (e.g., low density per unit volume, high strength, and not toxic, and not harmful to the skin). It should also be noted that the results of the mechanical tests, demonstrated in Table 1, differ from each other due to the difference in fabrication method, matrix materials, and fiber types and weight ratios.

2. Experimental Testing and Setup

2.1. Raw Material Preparation. In the present study, the raw materials were chosen from plastic scrap (i.e., thermoplastics RP such as polyethylene and polypropylene) as the matrix and DPF for reinforcement in order to synthesize polymer-DPF composites.

2.1.1. Matrix Material. The most important thermoplastics include low- and high-density polyethylene, polypropylene, polyvinyl chloride, and polystyrene [26]. Thermoplastics are used in many applications such as wires and many structures of mechanical parts and can be used effectively as a matrix for natural and synthetic fibers [27]. By reheating the plastics, it can be formed or reshaped according to the used molds. In this study, polyethylene and polypropylene polymers are recycled with a temperature below 230°C. Sorting, shredding, washing, softening, and shaping have been performed as the first steps to prepare the matrix material of composites.

2.1.2. Reinforced DPF. The reinforced material was chosen in this study to be DPF from leaf sheath. The DPF was obtained from a local Saudi date palm. The chemical composition was 43-46 wt% cellulose, 18-24 wt% hemicellulose, 20-28 wt% lignin, 5-10 wt% ash, and 2-11 wt% moisture content [13, 14, 28]. The mechanical properties of natural fibers depend on the central void, porosity, helical angle, and two degrees of crystallinity [29]. The DPF were collected in ethylene plastic containers. The samples were then washed with water and then alkali treatment (with 5 wt% NaOH solution for 30 min) has been done to improve the RP and DPF interfacial adhesion. At the room temperature, fibers were dried and then cut into average lengths of 2.5 to 10 mm using a sharp blade. After initial drying, they were dried again in a vacuum oven at 40°C for 12 hours. Then, fibers were kept in an insulated and emptied container for the time of use. Only fibers up to 0.3 mm in diameter were used for this study.

2.2. Mold Fabrication. Iron compression mold of dimensions 30 cm × 19 cm × 3 cm was fabricated by a CNC milling machine. The machining process has been conducted for specimen's cavities, prepared for tensile, impact, and creep tests, according to the standard dimensions of GUNT mechanical testing machine. In fact, three main shapes were

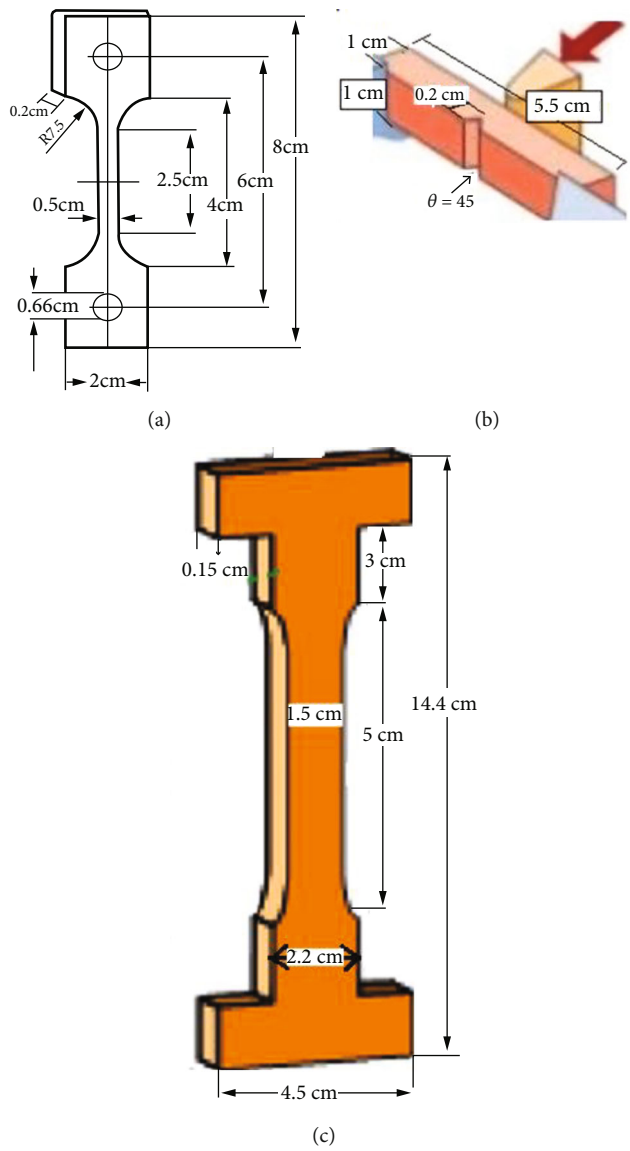


Figure 2: Specimens' dimensions for (a) creep, (b) impact, and (c) tensile tests.

Table 2: Raw materials used to prepare the specimens.

Specimen no.	RP content (wt%)	DPF content (wt%) with different lengths (2.5-10 mm)
1	95%	5%
2	90%	10%
3	85%	15%
4	80%	20%

needed for testing and were fabricated using iron compression mold. The iron compression mold, as shown in Figure 1, can be reused several times in molding the specimen. The dimensions of specimens, prepared for creep, impact, and tensile tests, were chosen according to the American Society for Testing and Materials (ASTM): standards D638 and D6110 [30] (refer to Figure 2).

The completed mold needs a high attention to ensure a smooth release of the composite when it cures in the mold. For the first time, five layers of wax were required to ensure that the surface is fully covered. After that, only two layers of wax were sufficient to remove the composite from the mold easily.

2.3. Composite Preparation and Characterization. RP-DPF composites were prepared according to different weight ratio and lengths as shown in Table 2. Five steps have been performed to prepare the specimen for testing: (i) softening, (ii) adding the reinforcement, (iii) mixing using a stir technique, (iv) pouring the mixture into the mold, and (v) cutting of specimens.

The electrical furnace used for testing contained a cylinder with a 100 mm inner diameter, 150 mm height, and 10 mm thickness. This cylinder is made of graphite crucible and covered by iron lid. The purpose of using the stirrer rod

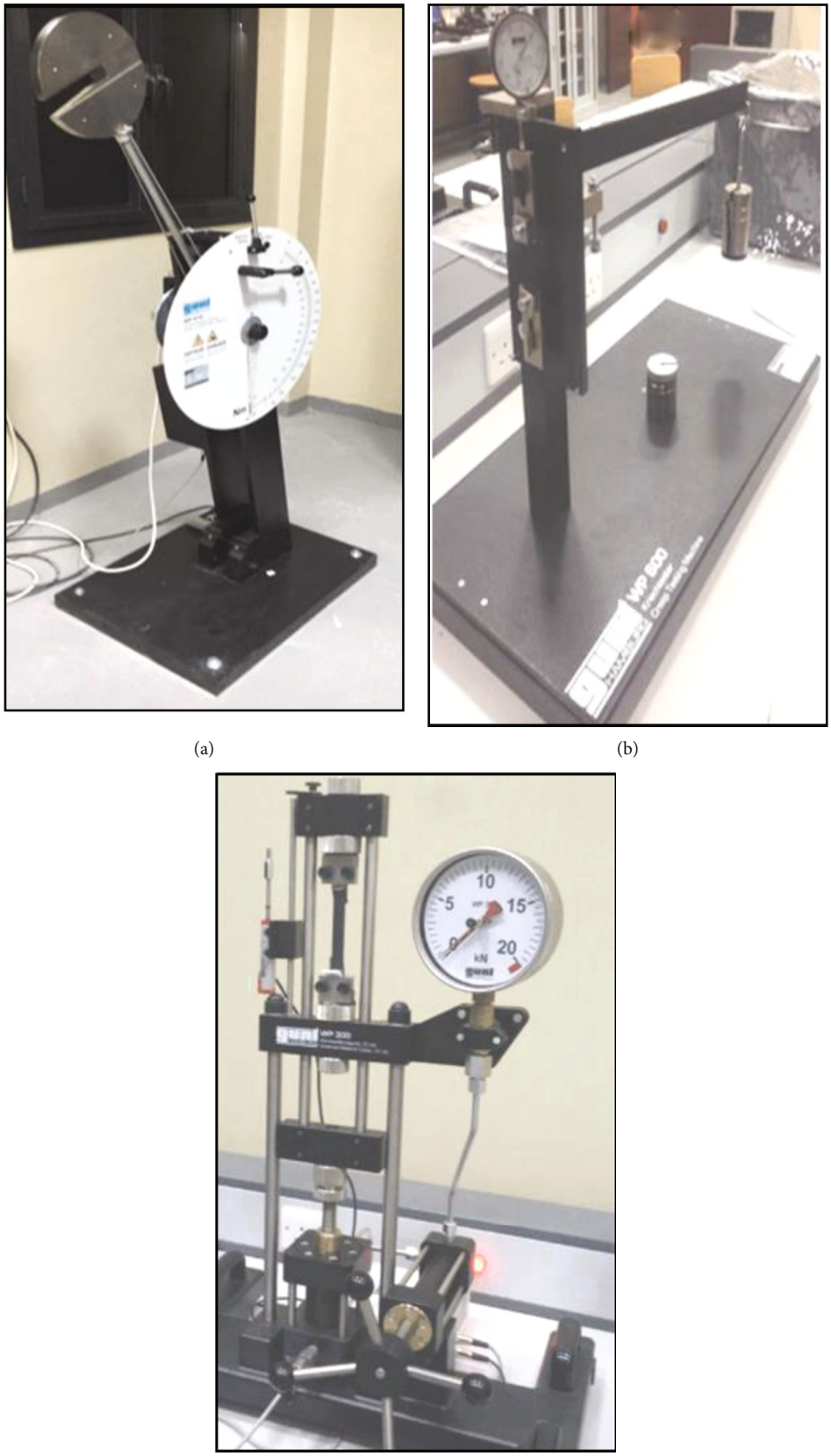
Figure 3: Different types of specimens with different lengths and weight ratios of DPF.

was to mix and distribute the added DPF in the thermoplastic matrix with slow motion and steady stirring to ensure that the mixing is done without formation of air bubbles (i.e., porosity). Plastic softening temperature ranged from 80 to 90°C and melting point ranged from 110 to 130°C. The reaction between plastic and oxygen started at 140°C in order to break the bonds in the main chain. The heating rate was 10°C/min, and the temperature was held at 80°C to make the plastic have high ductility. At 90°C, the DPF were added gradually for 10 minutes and held for 30 minutes with regular stirring to ensure a good homogeneity and wettability between the DPF and thermoplastic matrix. After getting the DPF homogenous, the DPF composite was compressed in an iron mold as shown in Figure 1. Before compressing the composite into the mold, it was necessary to reheat it, in order to improve the ductile condition, and restir it. These processes were repeated many times to fabricate different types of specimens with different lengths and weight ratios of reinforcements as shown in Figure 3.

Vickers hardness machine with a load of 60 kg was used for 5 seconds to investigate the influence of lengths and weight ratios of reinforcements on the DPF-polymer composite hardness. Four different testing points were taken for each specimens, and the average value was taken to eliminate any errors due to local nonhomogeneity. The four specimens were used to determine the average value of each property. The impact, creep, and tensile tests were carried out by using GUNT WP 410, GUNT WP 600, and GUNT WP 300 machines, respectively, as shown in Figure 4, in order to investigate the influence of lengths and weight ratios of reinforcements on DPF-polymer composites.

3. Results and Discussions

3.1. Hardness Test. Hardness measurement is one of the most rapid methods to determine the mechanical properties (i.e., tensile and impact strengths, creep, and wear) of the composites. Improvement of hardness depends on the amount, length, and uniform distribution of DPF. The results for average hardness values for different types of RP-DPF composites are shown in Figure 5.



(a) (b) (c)

Figure 4: Machines used for testing: (a) impact GUNT WP 410 machine, (b) creep GUNT WP 600 machine, and (c) tensile GUNT WP 300 machine.

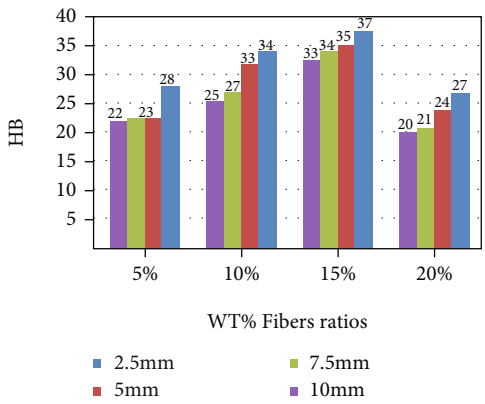


Figure 5: Average hardness values for RP-DPF composites for different lengths and weight ratios of DPF.

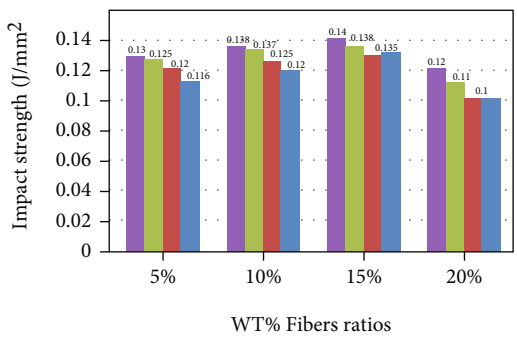


Figure 6: Impact strength for different lengths (2.5, 5, 7.5, and 10 mm) and different weight ratios (5 wt%, 10 wt%, 15 wt%, and 20 wt%) of DPF in the tested RP-DPF composites.

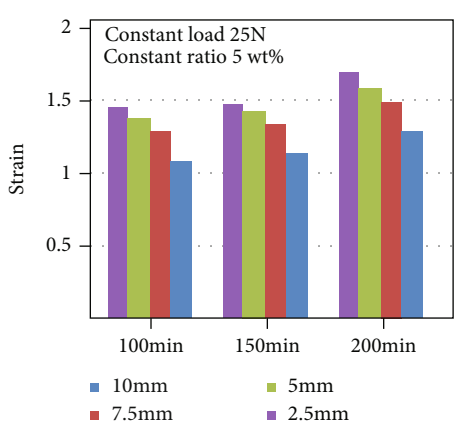


Figure 7: Strain values of RP-DPF composites for different lengths with constant weight ratio of 5 wt% and constant applied load of 25 N for different strain times.

In general, the hardness of RP-DPF composites with a 10 mm fiber length is less than the hardness of RP-DPF composites with other lengths of fibers (i.e., 2.5, 5, and 7.5 mm) at the same weight ratios (i.e., 5, 10, 15, and 20 wt %). In fact, the hardness of the RP-DPF composites with 10 mm fiber length and weight ratios of 5 wt%, 10 wt%,

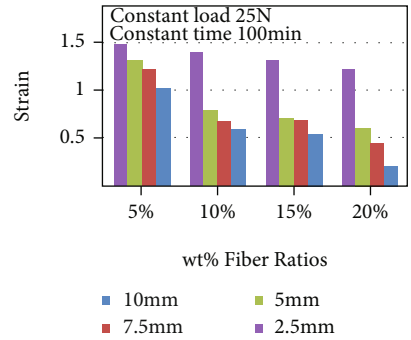


Figure 8: Strain values of RP-DPF composites for different lengths with different weight ratios and strain times and constant applied load of 25 N for 100 min strain time.

and 15 wt%, was 22, 25, and 33 HB, respectively. In other words, as the weight ratio increases, the hardness increases. With weight ratios of 20 wt% and fiber lengths of 2.5, 5, 7.5, and 10 mm, the lowest values of the hardness can be achieved. The highest hardness was observed to be 37 HB for the RP-DPF composites with 2.5 mm fiber length and weight ratio of 15 wt%. In general, the hardness results showed that shorter fibers have higher hardness in comparison with long fibers due to the good distribution of shorter fibers in comparison with the long fibers. Hardness also increases with increasing the content of DPF due to the high content of lignin, which refers to an irregular polymer chain (i.e., organic substance) that increases the strength and stiffness of RP-DPF composites. In the results proposed in this study, the contents of DPF and lignin were 15 wt% and 45 wt%, respectively. In addition, good interfacial bonding between the DPF and RP leads to higher strength of the composites [31–33]. The hardness of the RP-DPF composites with 20 wt% DPF decreases due to the less distribution of the agglomeration in the DPF, formation of porosity with a high amount of impurities during the mixing process, weak interfacial bonding between the RP and DPF in some parts, and disappearing of the RP matrix among fibers (i.e., weak mechanical properties). There is also a noticeable effect on the hardness due to the increase in gas bubbles within the matrix caused by the stirrer speed.

3.2. Impact Test. The improvement of the mechanical properties of the composite depends on the properties of the matrix and fibers. The impact test provides information about the bearing capacity of the composite to absorb shock before fracture. Therefore, brittle materials have less shock energy absorption in comparison with ductile materials. The toughness of materials is directly affected by the weight ratio and properties of toughness for both fibers and matrix, as well as the interfacial region and the withdrawal of fibers from the matrix [34–36]. In general, the impact increases with increasing the weight ratios and lengths of DPF as shown in Figure 6.

In order to obtain a good impact measure, appropriate bonding and adhesion levels are required. Effective stress transfer between fibers and the matrix depends on the length of fibers. It should be noted that the length of fibers is critical

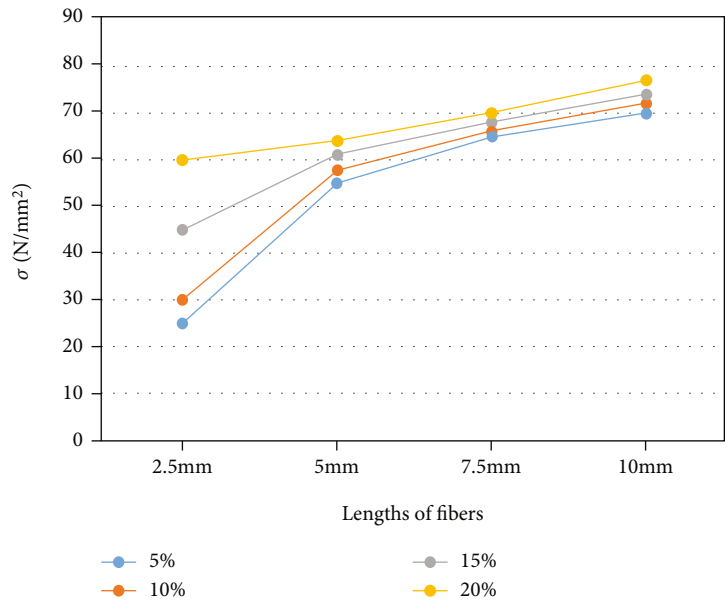


Figure 9: Tensile strength for different lengths and different weight ratios of DPF in the RP-DPF composites.

so that they should not be less than a certain value in order not to lead to a sample failure due to debonding at low loads. On the other hand, for fiber lengths larger than the critical length, the applied load leads to effective stress transfer between fibers and the matrix. Thus, higher impact strength can occur [37]. Random distribution of fibers with strong interfacial adhesion between RP and DPF leads to significant crack propagation resistance [38].

From the results in Figure 6, the impact strength, tested for 2.5, 5, 7.5, and 10 mm lengths, increases with increasing the DPF up to ratios of 15 wt%. Increasing the weight ratios and length of DPF increases the impact strength. Note that tough DPF with strong interfacial adhesion between RP and DPF in addition to the existence of fiber lengths that are greater than the critical length with good random distribution of DPF will achieve good stress transfer from the matrix to fibers. The impact strength of composites for different DPF lengths with 20 wt% DPF decreased due to the less distribution of agglomeration in DPF, porosity with high amount of impurities, and weak adhesion between RP and DPF due to the disappearing of RP matrix among fibers that certainly leads to lower stress transfer.

3.3. Creep Test. The strain variation with respect to time under a continuous loading can be used to measure creep. The most important factors that may affect the creep rate of composites are the fiber length, weight ratio, interaction with the matrix inside the composites, temperature, humidity, and the level of stress applied to the composite. Increasing the fiber content and the interfacial interaction between fibers and the matrix reduces the creep rate [39]. One of the challenges of replacing metals with thermoplastics is that many structural parts need to be rigid and provide high impact strength and low creep rate.

Figure 7 shows the strain values of RP-DPF composites for different lengths with a constant weight ratio of 5 wt% and constant applied load of 25 N. Initially, the creep rate is relatively high, while it decreases rapidly with time, which could be due to slipping and orientation of the polymer chains under constant stress. In addition, after the primary creep (i.e., high creep rate), the creep reaches a constant rate in the secondary creep stage. With a low stress level, the polymer may stay longer in this stage. In the final stage, creep rate increases again, leading to fracture of the material.

The creep strengthening is associated with the load transfer from the matrix to reinforcements. Fiber length and content both have significant effects on stress state. Short fibers reduce the maximum stress where long fibers have better stress transferring action than the short ones. Creep resistance increased by increasing the length and content of fiber as shown in Figure 7. Random orientation, good distribution, and long fibers with strong interfacial adhesion between RP and DPF raise significantly crack propagation resistance, which improves creep resistance [38, 40]. Many microfailure modes occurred during creeping such as fiber pulled out, fiber breakage, interfacial debonding, and matrix cracking, which lead to increasing the creep rate. By improving microfailure modes, the creep rate can be decreased.

From Figure 8, the strain decreased with increasing the DPF length and content. The strain for shorter fibers (i.e., 2.5 mm) of 2.5 mm with 5 wt%, 10 wt%, 15 wt%, and 20 wt % DPF content were 1.4, 1.3, 1.2, and 1.1, respectively. The maximum strain was obtained using the length of 2.5 mm and 5 wt% DPF content due to the ductility of the plastic matrix. With a small ratio of tough DPF, short fibers were also unable to block or resist rapid plastic deformation in specimens. The strain of long fibers (i.e., 10 mm) with 5 wt %, 10 wt%, 15 wt%, and 20 wt% DPF content were 0.97, 0.56, 0.5, and 0.2, respectively. The minimum strain was obtained using the length of 10 mm and 20 wt% DPF content. It was obvious that the content and length of fibers improve transferring action.

3.4. Tensile Test. Many researchers reported that adding natural fibers in a polymer has a significant effect on the tensile strength properties. In general, the tensile strength of the RP-DPF composites increase with increasing the fiber length and content as shown in Figure 9. When the matrix is reinforced with materials such as fibers or even metal powder, a decrease in ductility is observed and hardness is affected. From Figure 9, the tensile strength increases with increasing the DPF length and content in RP matrix. The tensile strength of shorter fibers (i.e., 2.5 mm) with content of 5 wt %, 10 wt%, 15 wt%, and 20 wt% DPF content were 26, 30, 45, and 60 N/mm^2, respectively. The minimum strength was obtained using a 2.5 mm length and 5 wt% DPF content due to ductility of the plastic matrix. A small weight ratio of stiffer short DPF reduces the maximum stress level. In addition, it was not able to hinder or resist crack propagation [39–41]. The tensile strength for long fibers (i.e., 10 mm) with 5 wt%, 10 wt%, 15 wt%, and 20 wt% DPF content was 70, 72, 75, and 78 N/mm^2, respectively. The maximum strength was obtained using a length of 10 mm and 20 wt% DPF content due to the fiber length and content that improve transferring action and microfailure modes. Reinforcement changes the paths and propagation of microcracks and fracture behavior. The changes in fracture behavior mainly occur because stress is transmitted along the material through the matrix and fiber interface. Thus, the interaction and adhesion of materials (i.e., the reinforcement and the matrix) and their general properties, including the surfaces of the reinforcement, have an important role in cracks and their occurrence. When a tensile load is applied directly to the samples, too much stress will be exerted on the fibers causing the weak fiber to fail. As the load continues, the intact fibers fail and stress shifts to the matrix leading to a failure.

4. Conclusions

A RP reinforced with various weight ratios of DPF was synthesized and characterized successfully. The mechanical properties such as hardness, impact, creep, and tensile strength are observed to be affected by DPF length and content. The results show that composites prepared with shorter fibers have higher hardness than those composites prepared with long fibers. The results also show that the hardness of the produced composites increases with increasing the fiber content up to 15 wt%. In addition, the impact strength increases with increasing the DPF length and content up to 15 wt%. The hardness and impact strength of composites with different DPF lengths and 20 wt% DPF content decrease due to the less distribution of agglomeration in DPF, porosity with high amount of impurities, and poor interfacial adhesion between the RP and DPF due to the disappearing of the RP matrix among fibers. The strain decreases with increasing the DPF length and content. The strain of the composites prepared with short fibers (i.e., 2.5 mm) and different fiber content (i.e., 5 wt%, 10 wt%, 15 wt%, and 20 wt%) were 1.4, 1.3, 1.2, and 1.1, respectively. The highest strain was obtained from a fiber length of 2.5 mm and 5 wt% DPF content due to ductility of the plastic matrix and the presence of a small ratio of tough DPF. Short fibers are also unable to block or resist rapid plastic deformation in specimens. The minimum creep and maximum strength were obtained using a fiber length of 10 mm and 20 wt% DPF content. It was clear that fiber length and content improve transferring action and microfailure modes.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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