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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

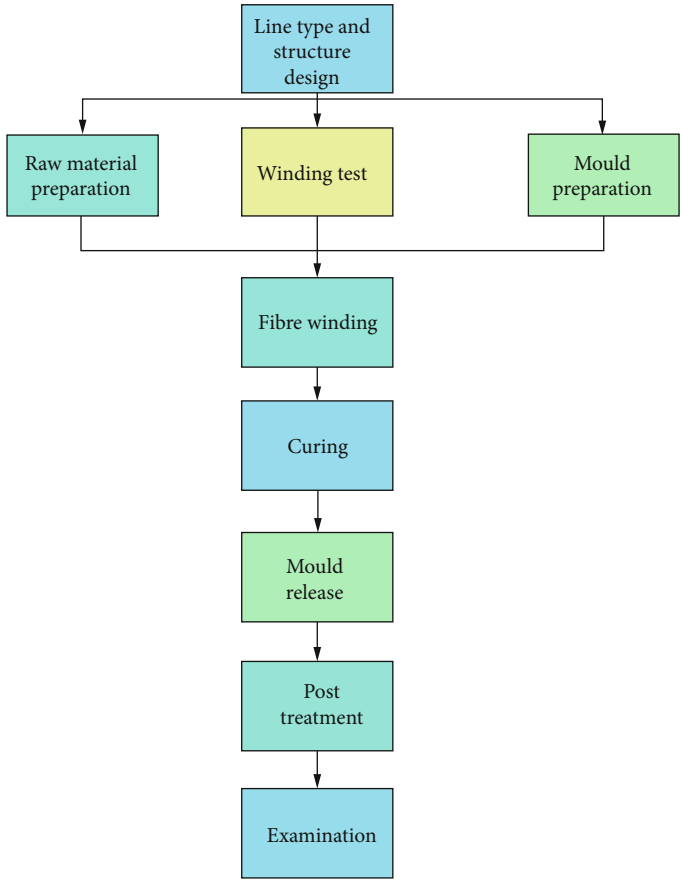


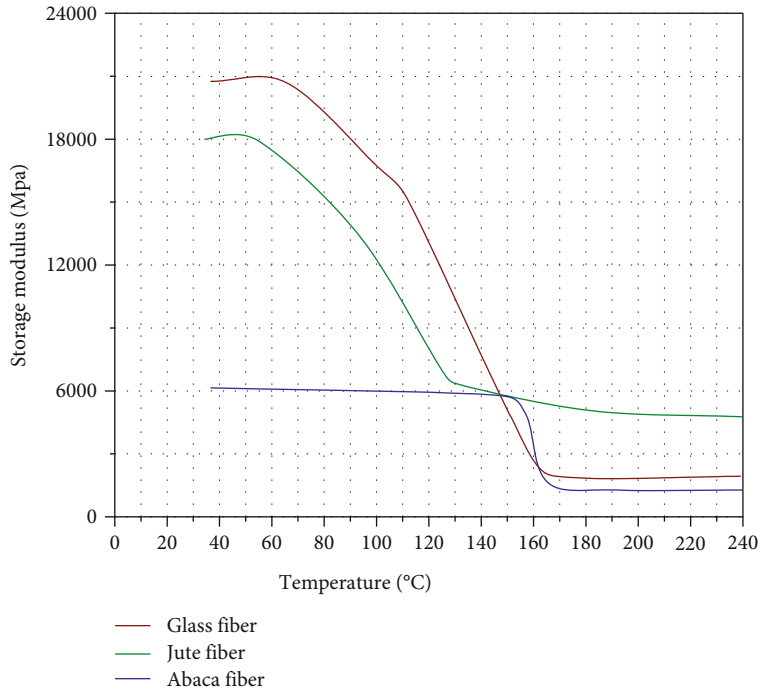
Figure 1: NOL ring fabrication preparation.

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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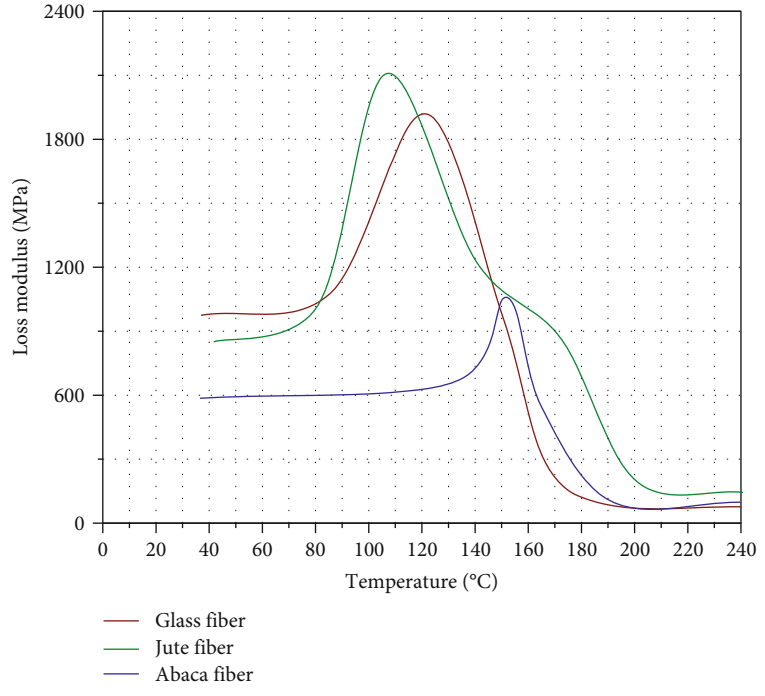

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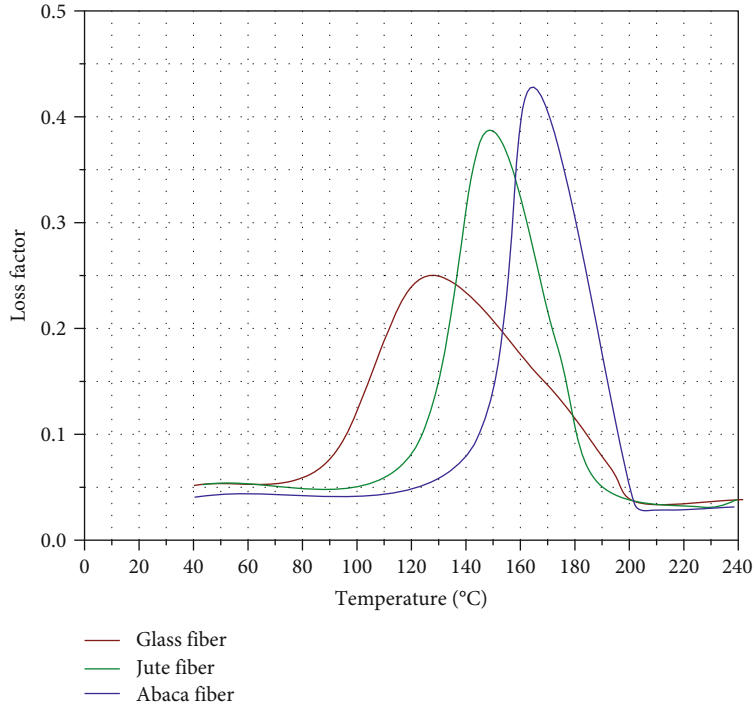

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Figure 2: (a) Storage modulus. (b) Loss modulus. (c) Loss factor of circumferential composites at a single frequency.

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.

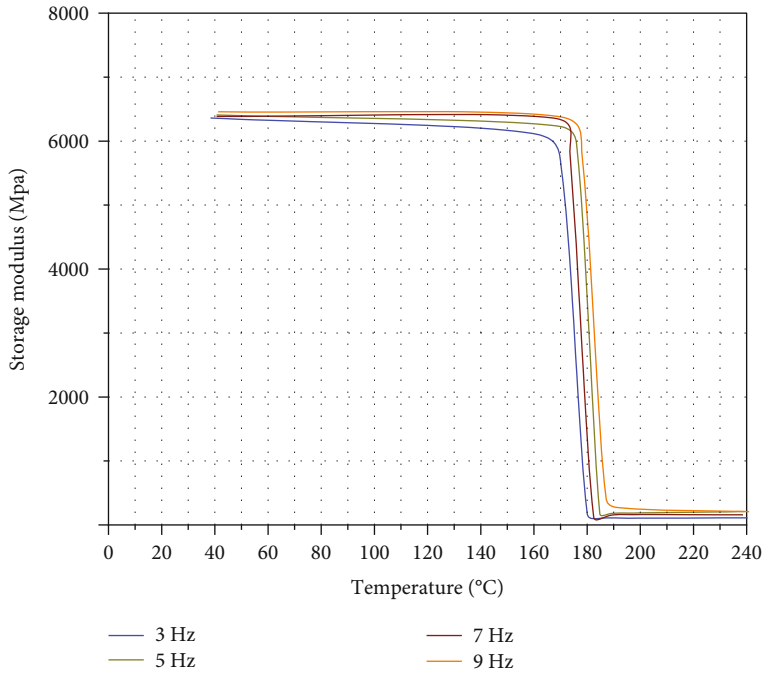
Using a hoop winding naval ordnance laboratory ring, filament winding composites' fiber characteristics and resin interface were studied. It provided fundamental winding composite process characteristics while also reflecting filament winding composites' structure and performance [18]. For the purposes 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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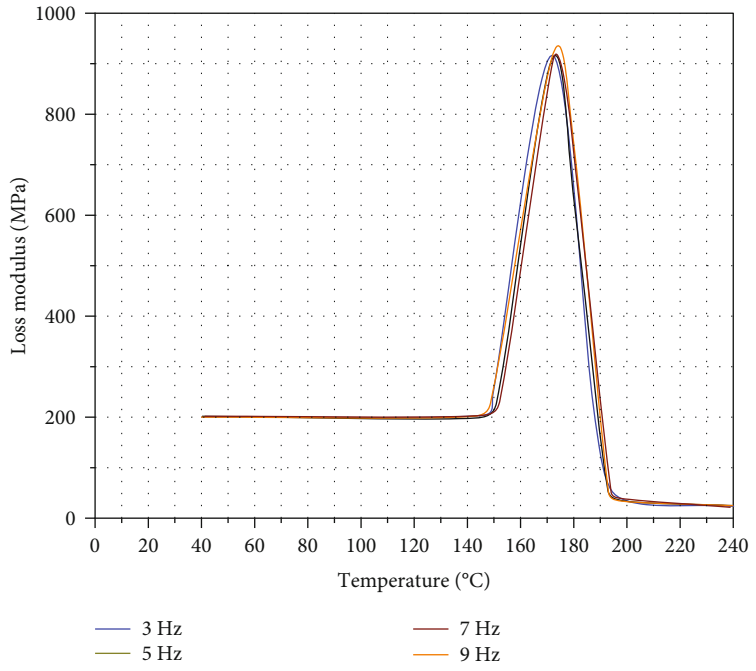

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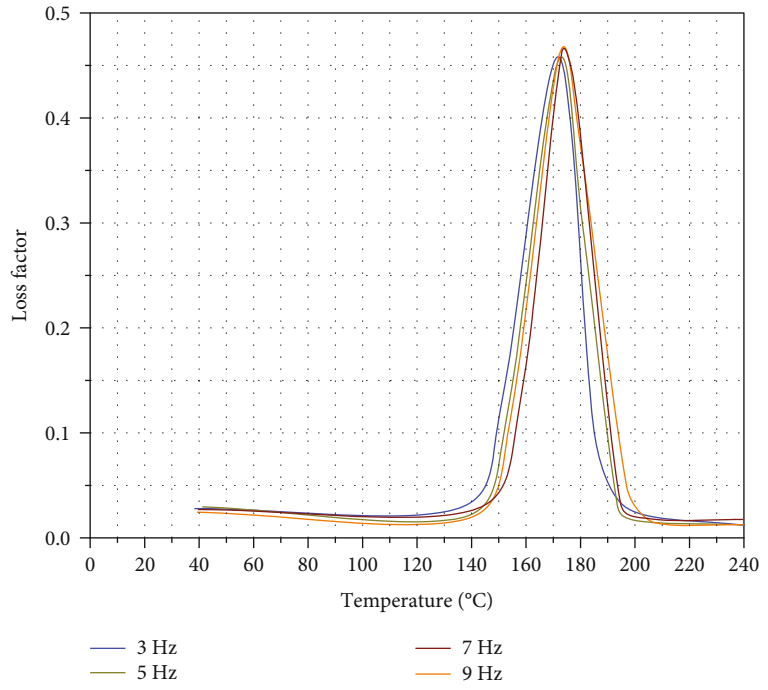

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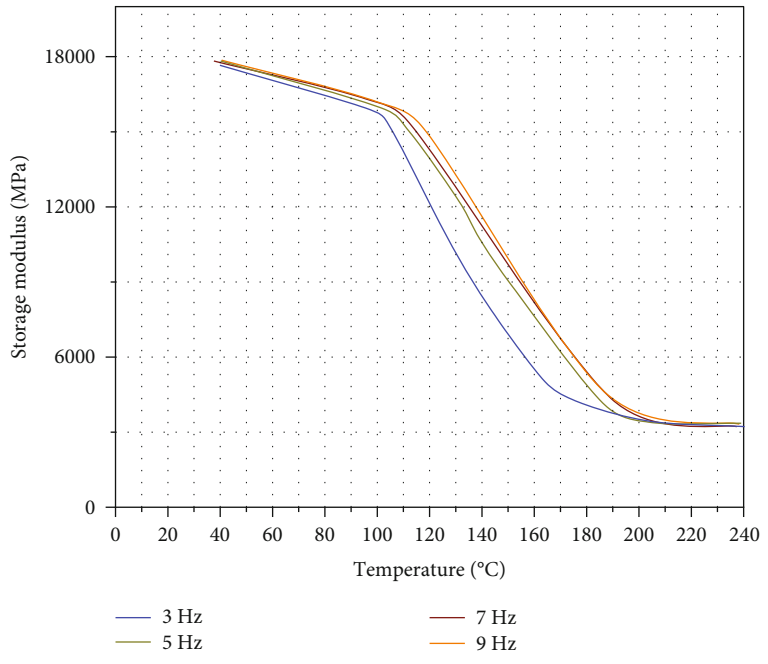

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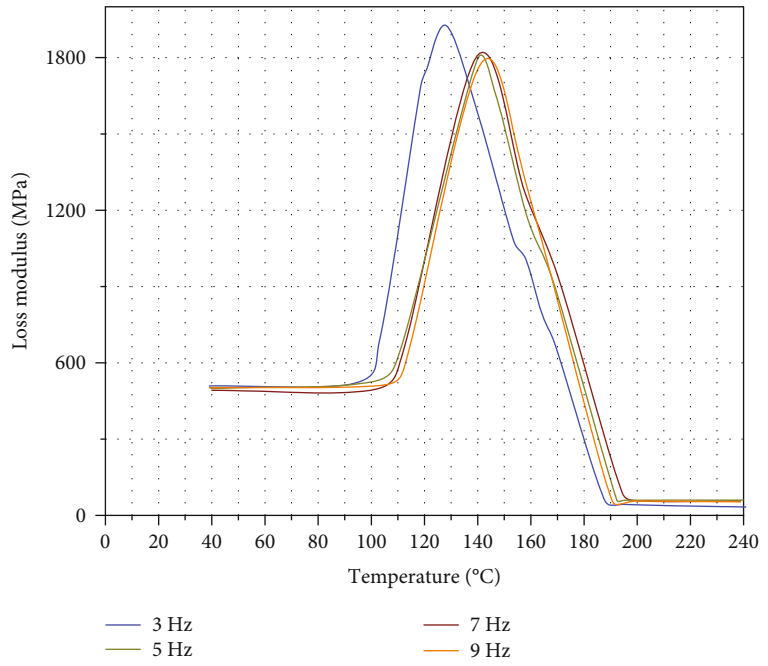

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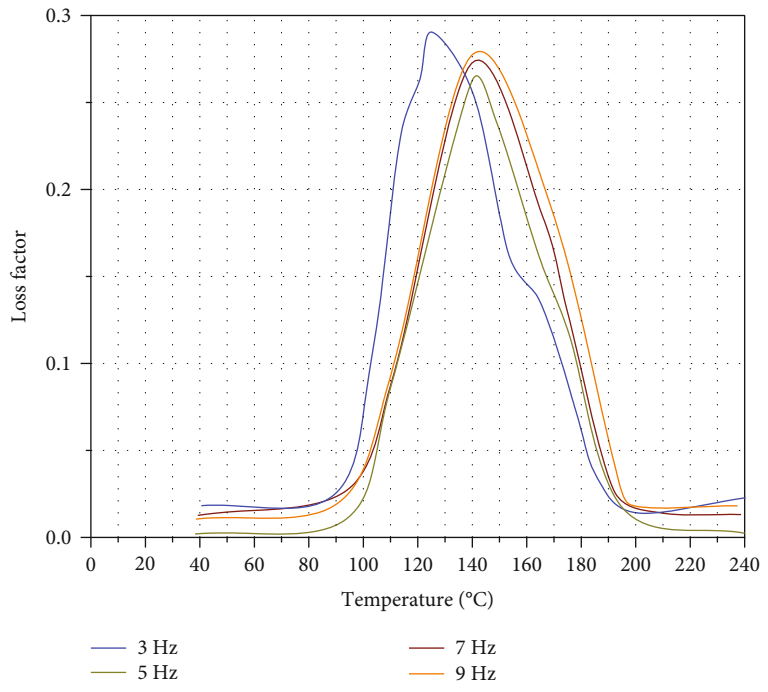

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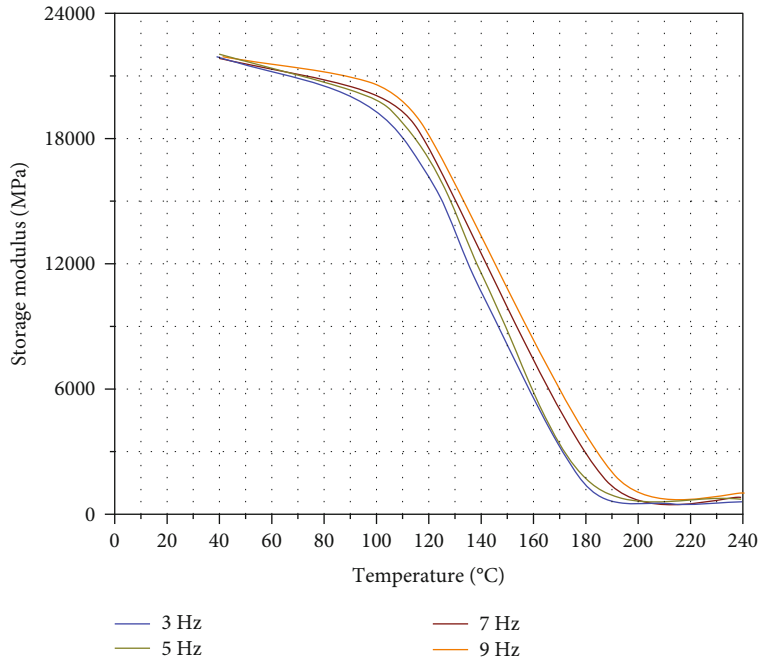

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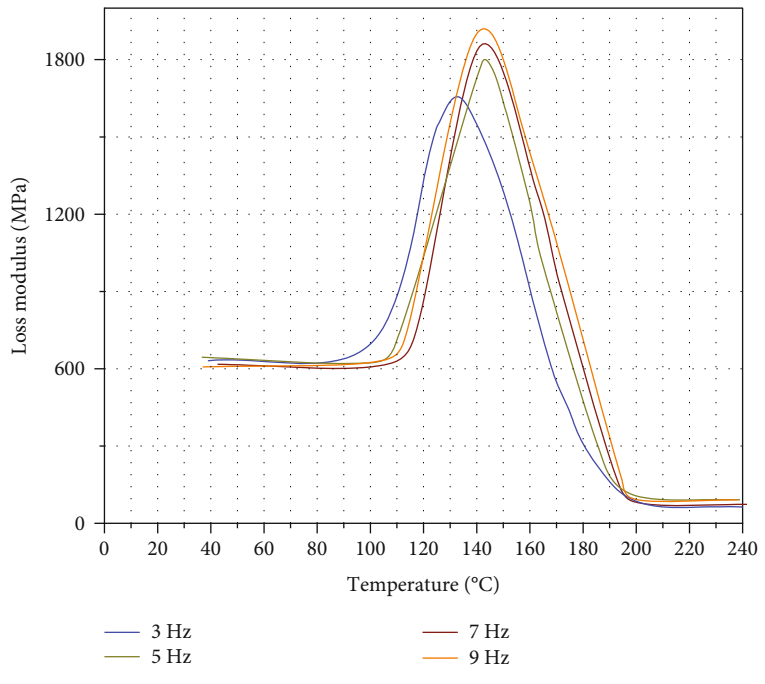

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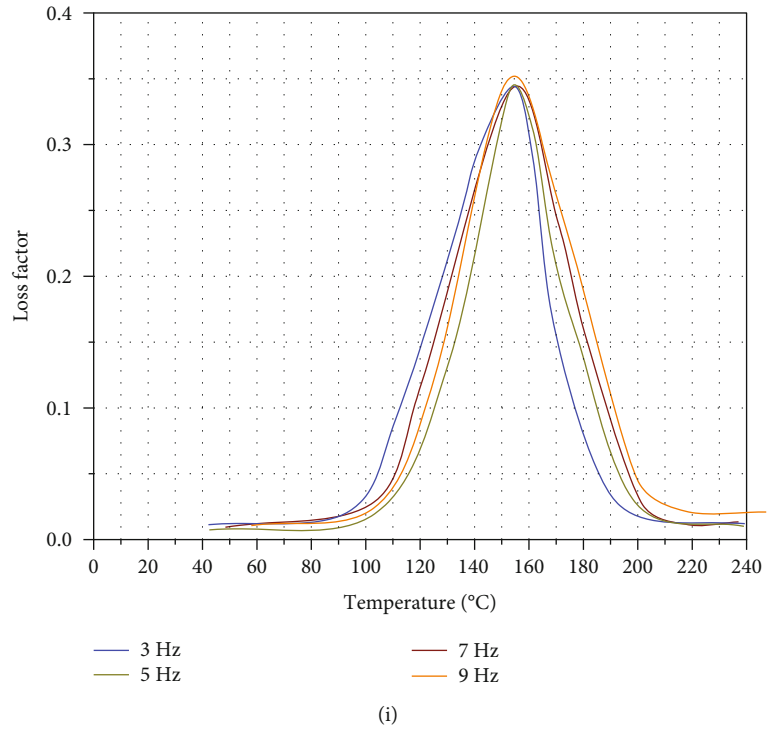


(i)

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

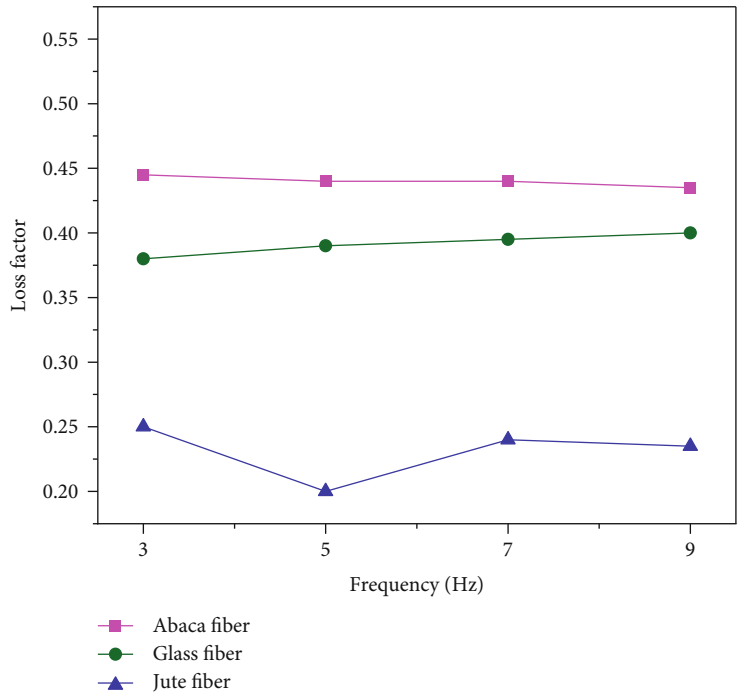
yet. Just keep the winding shaft spinning. While the online curing unit is running, the naval ordnance laboratory ring's surface temperature should be kept at 120°C for 30 minutes. Samples should be removed and postprocessed as soon as surface temperatures of the naval ordnance laboratory rings are lower 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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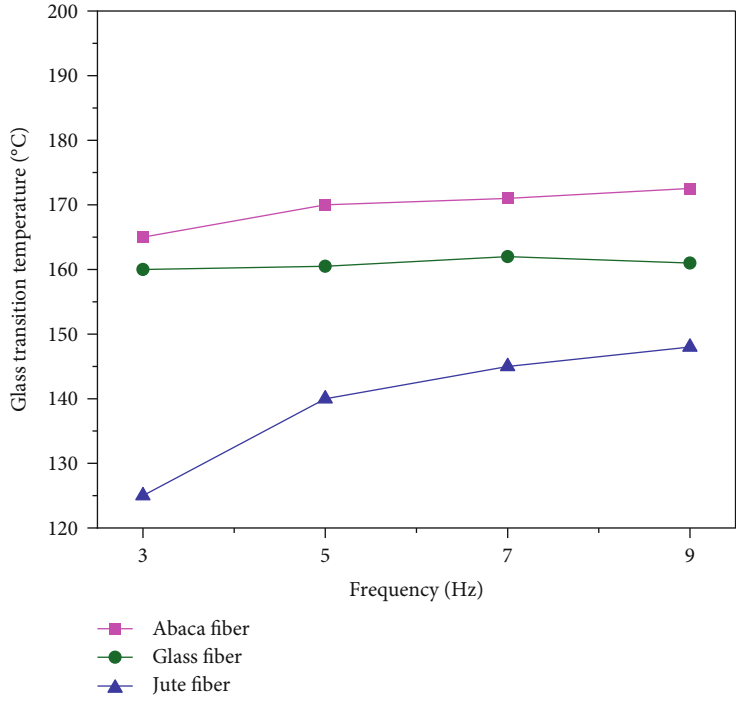

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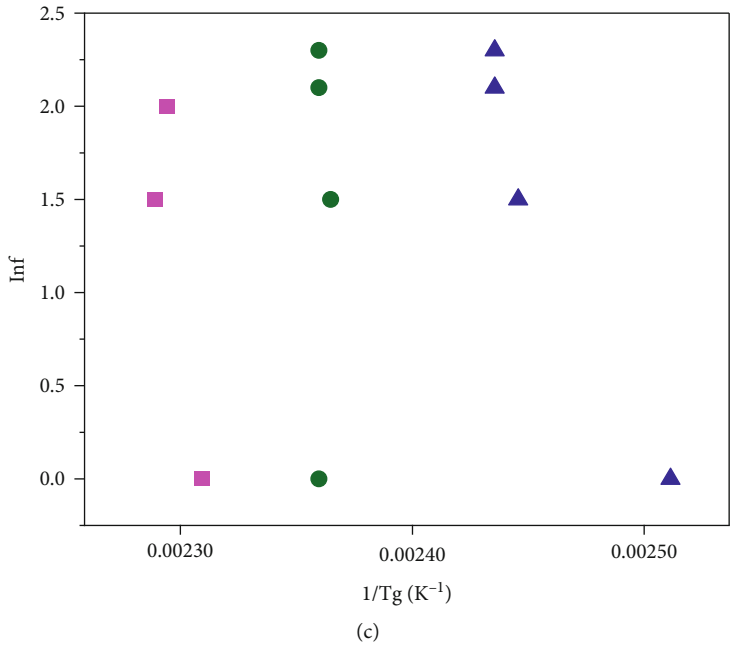

Figure 4: Circumferential composites have varying loss factors and Tg at variant frequencies. (a) Loss factor vs. frequency. (b) Tg vs. frequency. (c) Apparent activation energies of circumferential composites.

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.

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

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.

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