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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

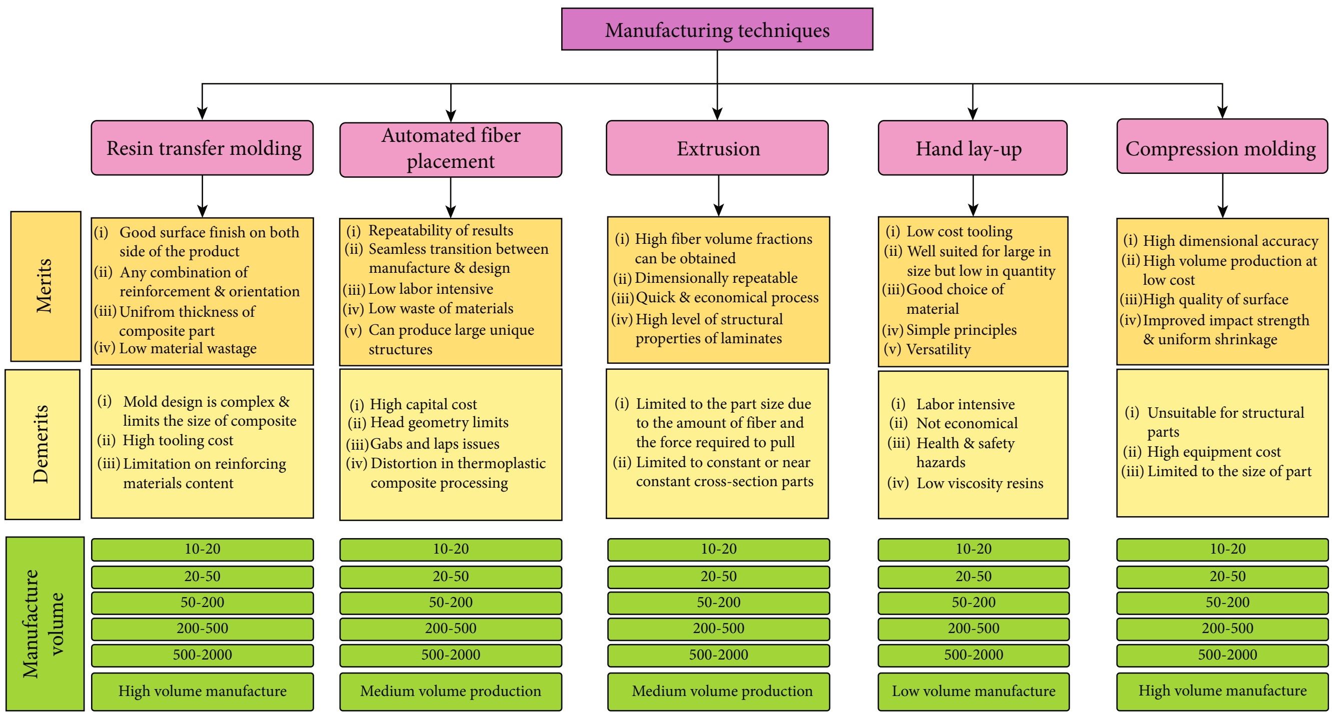

Figure 1: Manufacturing techniques of polymer composites.

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 $200 \times 200\,mm^2$ 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

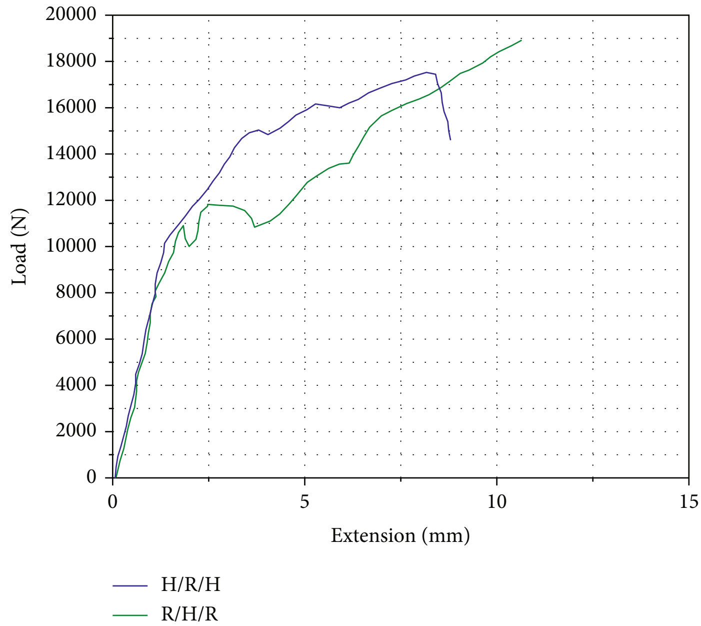

Figure 3: Load–extension curve for hybrid composites.

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

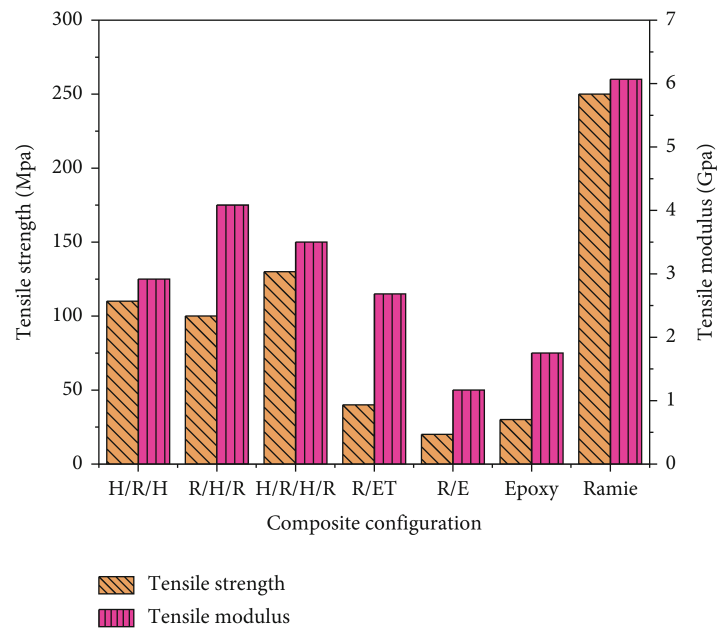

Figure 4: Tensile strength and modulus of R/H hybrid composites, R/E, pure epoxy, and H/E.

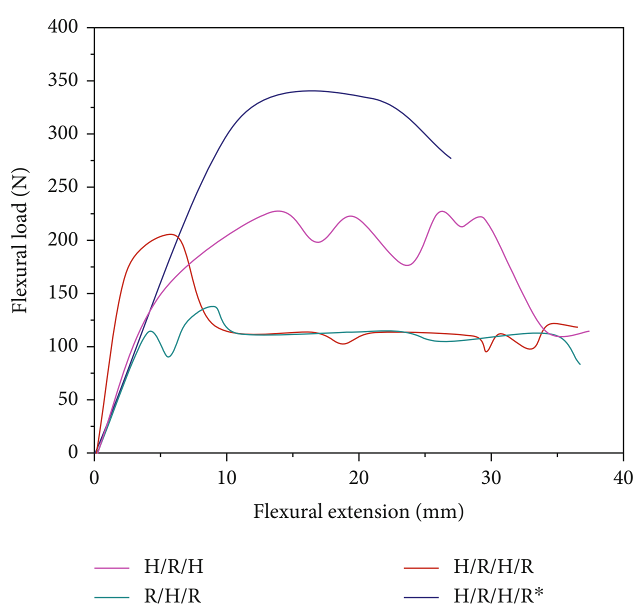

Figure 5: For hybrid composites, the flexural load–extension curve.

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

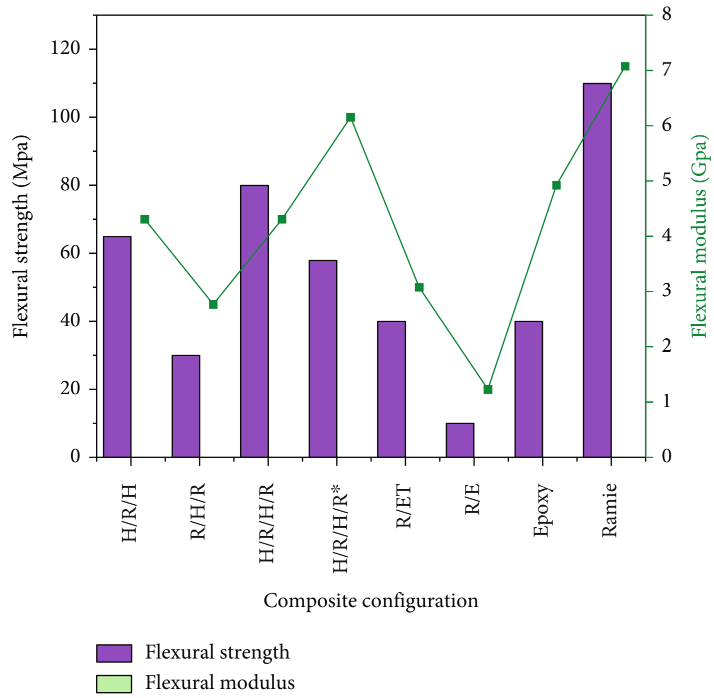

Figure 6: Flexural strength and flexural modulus of R/H hybrid composites, R/E, pure epoxy, and H/E.

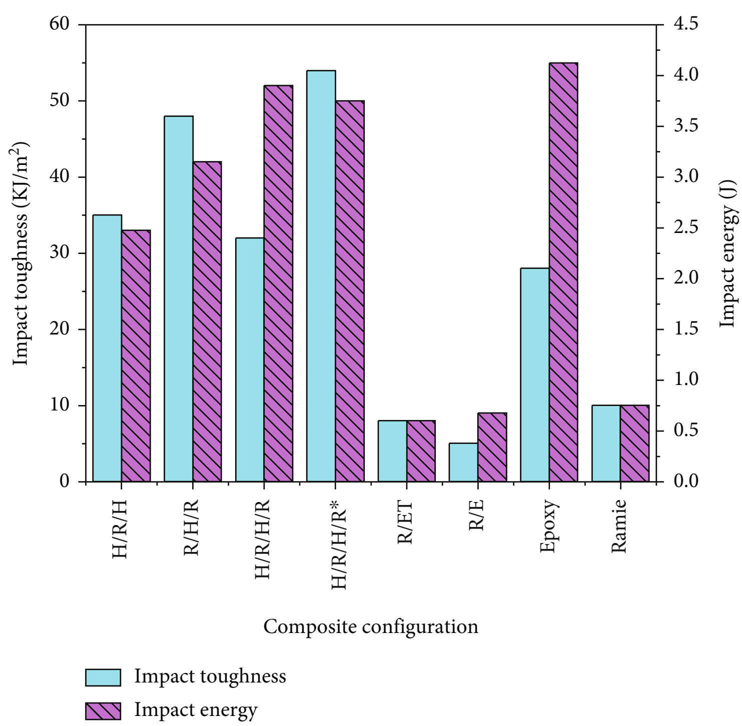

Figure 7: Impact energy and toughness of R/H hybrid composites, R/E, pure epoxy, and H/E by Charpy impact tests.

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.

Acknowledgments

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