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Materials Research Express

OPEN ACCESS

RECEIVED
6 July 2023

REVISED
26 September 2023

ACCEPTED FOR PUBLICATION
12 October 2023

PUBLISHED
20 October 2023

PAPER

Mechanical and dynamic mechanical properties of hybrid kevlar/natural fiber composites

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Keywords: kevlar fibre, hybrid composites, dynamic mechanical analysis, mechanical p roperties

Abstract

The current experiment aimed to identify the characteristics of composite materials enhanced with aloe vera, bamboo, palm, and kevlar fibres. Three different types of combinational fabrication—Type I (a blend of aloe vera and bamboo), Type II (a combination of bamboo and palm), and Type III—were carried out from all the other them (blend of palm and aloe vera). Analysis was done on the mechanical and dynamic-mechanical evaluation of biocomposites made spontaneously. Natural fibres used to produce hybrid composites were alkaline and treated in a 2.5 ml NaOH solution for 6 h at room temperature to get acceptable characteristics, then dried to remove the wax and oils on the natural fibre's exterior surface. The effect of different stacking sequences on the mechanical and dynamic properties of manufactured composites has been investigated experimentally through ASTM standards. Impact, inter-delamination and double-shear tests are used to evaluate the mechanical properties; the failure mechanisms of the fabricated hybrid composites with various stacking sequences and testing conditions were investigated through the fractographs of SEM analysis. Type I S1 samples were found to display significant impact energy (10 Joules) as compared to other samples, and the break load of composite specimens was higher at 4.5 KN in S2 samples of type-III as compared to type-I and II, revealed Type-I samples with significant peak area of 0.492 delivered at 102.01 °C as compared to two types, Type-3 (Palmyra Palm + Aloe Vera) composite gave the best mechanical, dynamic properties.

1. Introduction

Natural fibre-reinforced composite materials are widely used in the automotive industry and manufacturing sector; natural fibres are extracted from plants and trees, natural fibre composite materials are biodegradable and eco-friendly, and different natural fibres are used for domestic and aerospace interior parts. Natural fibres used in composite materials are typically sourced from renewable resources such as plants (e.g., flax, hemp, jute, bamboo) or animals (e.g., wool, silk) [1, 2]. These fibres possess several advantageous properties, including high specific strength, low density, biodegradability, and natural abundance. They are often used in the form of fabrics or yarns. Natural fibres are derived from various plant and animal sources, serving as an essential element in human civilization's historical and modern fabric manufacture. These fibres have been employed for numerous millennia in producing textiles, ropes, and an extensive range of other commodities. Natural fibres commonly used include cotton, flax (or linen), silk, wool, and jute. These materials exhibit unique attributes, including biodegradability, breathability, and comfort, rendering them appealing options for a wide range of applications, encompassing clothes, home furnishings, and industrial and ecological purposes [3–6].

Findings showed that the flexure and tensile strength of the inter-oven hybrid composite were improved due to low sharing properties, and they also demonstrated the water absorption efficacy on the mechanical properties of mixed interwoven cellulosic-cellulosic composites fibre reinforced epoxy [7]. The water-resistant properties of oven kenaf, jute & hemp wool were upgraded. Correspondingly. Nevertheless, several researchers examined that regular.

Fibres can be efficiently utilized as filler/reinforced material in variabilities of thermoplastic and thermoset polymer composites for constructional and motorized applications [8–12]. The relative hybrid Sisal/Roselle/Banana fibre-reinforced qualities of epoxy composites were explored by Chandramohan *et al*, who also showed that composites are better for successful tensile and flexural loading [13]. The influence of fibre content on the mechanical and dynamic mechanical properties of glass/ramie polymer composites was a previous study that discovered a rigid interface between the fibre matrix at preeminent ramie fibre fractions and that mechanical properties were improved in significant fibre content [14–16]. Consuming renewable resources enables the development of sustainable 'green' environmental conditions. Natural fibres like kenaf, jute, hemp, sisal, pineapple leaf, date palm, and oil palm are plentiful worldwide and are regarded as waste materials [17–19]. The most crucial, delicate, and dominant thermomechanical method for determining the viscoelastic characteristics of composite polymers is dynamic mechanical analysis [20, 21]. According to research findings, hybrid composites can withstand collision and flexural loads better than single fibreglass-reinforced composites.

Additionally, fibre arrangement and orientation have a significant impact on fibre strength. Also, The hybrid fibre composites have a more substantial fraction (0.40) along with glass fibre, and the hybrid composite is suitable for all collective drives. Comparative evaluation of tensile strength of banana/ epoxy composites has higher (43.54%) tensile than polymer polyester (10%), which is significant than the banana bear fruit (30%) sophisticated than the hemp polyester composites [22–24]. Sisal fibre composite additions amplify the tensile strength of growing flexural strength up to 35% [25]. Expanding coherent interfacial attachment among the matrix and fibre improves the fibre-reinforced composite material performance. Besides, the composite materials treated with synthetic chemicals primes to adverse effects, including mechanical performance damage and surface degradation. Previous Investigation According to Badrinath *et al* [26–28], banana fibre is significantly stiffer than sisal fibre in both directions. Sisal fibre, in contrast to banana fibre, absorbs more water. Sisal bi-directional fibre has more flexural strength than banana fibre. Also, Banana fibre displays higher tensile strength in bi-directional in comparison to uni-directional patterns. There were morphological and physical properties attained by orientation properties as uni- & bi-direction patterns. Thus, their comparative evaluation suggests that the sisal bi-directional fibre has better tensile strength than the banana bi-directional fibre. Dynamic Mechanical analysis (DMA) is the most vital, delicate and operative thermos-mechanical method for characterizing the viscoelastic parameters of diverse composite materials [29–32].

Natural fibres have played a significant role in human culture and industry for an extended period. However, the contemporary focus on sustainability and environmental awareness has sparked a renewed enthusiasm for these materials. Researchers and industry are conducting the exploration of natural fibres as environmentally benign substitutes for synthetic materials to mitigate the environmental impact of a wide range of products. Not with standing this resurgence in interest, there remains a notable absence of study in all facets of natural fibres. Not many studies have been done to modify the mechanical and dynamic representation properties of Kevlar with standard fibre-reinforced epoxy composites at different framework proportions [33–35]. In keeping with this, the goal of the current Investigation was to determine the mechanical characteristics of composite materials strengthened with Aloe Vera, bamboo, palm, and Kevlar fibre using a vacuum-assisted resin transfer moulding process. The current findings will help identify potential uses for natural composites and the viability of their production, which will ultimately lessen our society's chemical burden.

2. Materials and methods

This experiment uses Aloe Vera, Bamboo, palm, and Kevlar fibres to create the composite specimen. The Anakaputhur Jute Weaver Association in Chennai, India, provided the mat-shaped Aloe vera, Bamboo, and Palm Fibers. Table 1 lists the physical characteristics of natural and kevlar fibres. The Kevlar fibre, epoxy resin (LY556), and hardener (HY951), both of which have densities of 0.97 to 0.99 g cm^{-3}, are bought from M/s—Javanthee Traders in Chennai, India. To increase the strength of hybrid composite, kevlar fibres are employed as outer layers. Epoxy and hardener should be combined at a 10:1 weight ratio to ensure effective interfacial bonding between fibres.

Table 1. Physical properties of aloevera, bamboo, palm and kevlar fibers [38].

Physical property	Aloevera fiber	Bamboo fiber	Palm fiber	Kevlar fiber 129
Density(g/cm3)	1.4	0.6–1.1	1.48	1.43
Tensile strength (MPa)	300	140–230	276	930
Elastic modulus (GPa)	45	11–17	3.85	53
Elongation at break (%)	2.5	1.4	12.8	1.6

Table 2. Sequence of composite laminates.

(TYPE -I)	(TYPE -II)	(TYPE -III)
Kevlar	Kevlar	Kevlar
Aloevera	Bamboo	Palm
Kevlar	Kevlar	Kevlar
Bamboo	Palm	Aloevera
Kevlar	Kevlar	Kevlar

Table 3. Formulation of reinforcement/epoxy composites.

Composite samples	Epoxy resin in wt.%	Reinforcement in wt.%
S1	70	30
S2	60	40
S3	50	50

2.1. Fabrication of composites

The composite specimen is made up of five layers, the top, middle, and bottom of which are fixed with Kevlar fibre layers, and the second and fourth layers filled with natural fibres like aloe, bamboo, and palm. The diamensions of mold size is used as 300 × 300 × 5 mm for fabrication of composite laminates. Figure 2 and table 2 display the different composites' fibre configurations. Natural fibres are alkaline treated in 2.5 ml NaOH solution for 6 h at room temperature and dried to remove the wax and oils found on the natural fiber's exterior surface. The natural fibres were then treated again with 2.5 ml NaOH solution and cooked at 75 °C for 3 h to remove lignin and hemicellulose, which improves the matrix-fiber interface and assures greater adhesion. Defibrillation and pore formation on the fibre surface were triggered by an increase in the concentration of NaOH solution. The natural fibres were rinsed four times with distilled water to remove the NaOH solution. The natural fibres were neutralised by boiling them in a 2% HCl solution at 75 °C for 4 h to eliminate residual hydroxyl. Finally, the fibres were submerged in 1% ethanol for 10 h before drying at 110 °C (Prakash Sampath *et al* 2019). In table 3, the matrix to fibre ratios for each hybrid composite are shown as 30:70, 40:60, and 50:50, respectively. Vacuum assisted compression moulding is used in this project because it is more dependable and effective than any other method. By creating a vacuum inside the shape so that the air trap cannot be framed inside the composite, this technology overcomes the drawbacks of other approaches. Figures 1(A), (B), and 1 show the various stages of this technique (C). A shield is initially created inside the shape constrain, as seen in figure 1(A). at that stage, each strand is separately placed as seen in figure 1(B). Finally, as shown in figure 1, the wood design with froth is used to condense the fibre layer (C).The manufactured composite overlay is then launched out of the form after the required blend has been framed and the shape has been allowed to dry for a period of five hours. Figure 2 shows the Design of composite configuration. Unwanted edges are ejected and cut to the necessary measurements when the composite example solidifies.

2.2. Mechanical testing

To assess the mechanical qualities of the constructed composites, impact, double shear, and delamination tests were also performed on all samples. The results of these tests are crucial in identifying the material's basic characteristics.

For impact tests with charpy layout, impact testing machines are employed. It is carried out to ascertain the composite's impact strength. This test also assesses the overall energy absorbed during impact and the material's disintegration, measured in joules. It is the determining factor that determines how long the composite specimen will last. With the aid of the oscillating pendulum, the specimen is struck suddenly, and the highest amount of energy absorbed during impact is recorded. The material's toughness affects how easily it fractures.

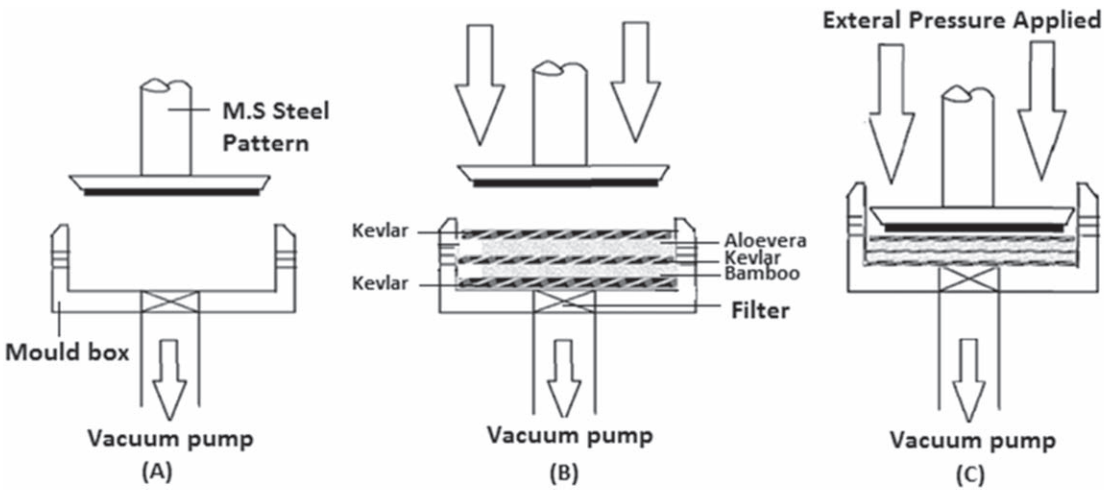

Figure 1. Vacuum assisted compression moulding; (A) Initial stage of mold and pattern,. (B) Arrangement of fibers in mold, and (C) Compression process.

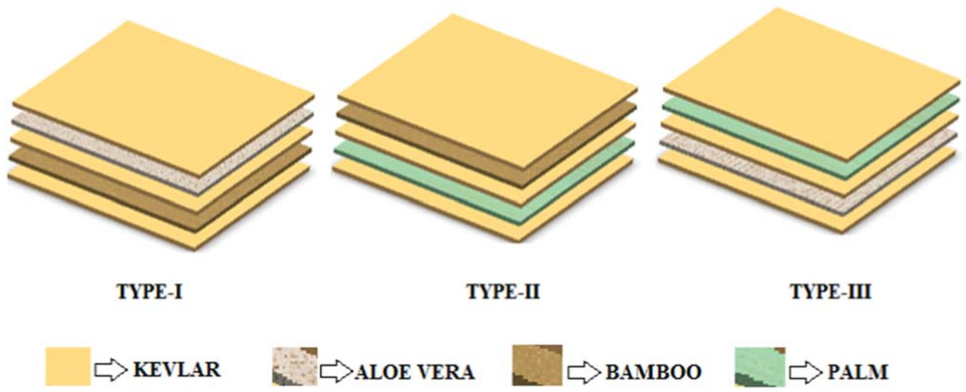

Figure 2. Design of composite configuration.

The blow that fails the specimen at a specific stage is applied. The greatest amount of energy that may be absorbed in joules is documented, and accompanying graphs have been drawn. a dual shear test was performed in accordance with the modified technique specified in standard ASTM: D5379. A fixture is used to hold the specimen while a steady load is applied to cause shear. Up until it breaks, the load is amplified, and the associated load is recorded. According to ASTM: D5528 standards, a delamination test is performed to assess the internal strength of the composite, which is the mode of failure when subjected to large loads and primes to layer separation. This separating causes the interior to weaken, which causes the portion to physically delaminate. The constant breaking load is resolute and the graph is drawn as the continuous load is put on the composite laminate until it cracks and delaminates. The details of the laboratory equipment used for double shear and delamination tests were experimental and conducted using a Universal Testing Machine (UTM) within the range of 0 to 40 T. The Charpy impact test was conducted using an Impact Testing Machine with a load range of 0–168 J, following ASTM D256 standards.The Institute of Plastic Technology in Chennai, India, used DMA Q800 V20.6 Build 24 to perform the dynamic mechanical analysis. Testing is conducted in bending mode at a 1 Hz frequency. For the experiments, rectangular specimens measuring 65 mm × 12.7 mm were cut from manufacture bi-layer composites. The experiment's target temperatures are 28 °C to 200 °C, with a heating rate of 4 °C per minute [36–38].

3. Results and discussion

3.1. Impact properties

The impact properties of natural composites were displayed in the figure 3 and table 4. The observation noticed that the impact energy of the Type-I (S1) category produced higher strength (10 Joules) as compared to S2 and S3

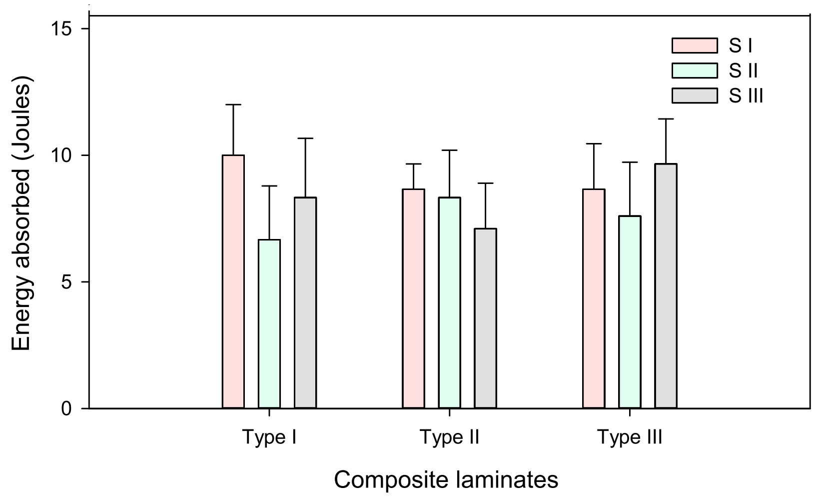

Figure 3. Result of impact test.

Table 4. The impact characteristics of the various samples.

Composite Samples	Energy absorbed (J)	Impact strength in Kj/m^2
(TYPE -I)		
S I	10	40.37
S II	8.66	30.96
S III	8.66	30.96
(TYPE -II)		
S I	6.66	26.89
S II	8.33	33.63
S III	7.66	30.93
(TYPE -III)		
S I	8.33	33.63
S II	7.00	28.26
S III	9.66	39.00

of Type-I category. Similarly, S2 samples of Type-II category displayed higher impact energy value (8.33 Joules) in comparison to S1 and S3 of Type-II category (figure 3(A)). Also, S3 samples were found to display significant impact energy (9.66 Joules) as compared to other samples of Type-III category. Overall, impact energy was superior in the Type-I (S1) samples as compared to other samples of Type-II and Type-III natural composites (figure 3). It has also been noted that the impact energy rose as the proportion of natural composites did. Previous results of Ramnath *et al* [4] showed that the higher impact energy was dependent on the fiber orientations.

3.2. Double shear test

The Double shear properties of the natural fibre composites were showed in the figures 4(A)–(C). The maximum displacement was observed at 33.75 mm in S2 samples of Type-I as compared to S1 (32.55 mm) and S3 (32.82 mm). Likewise, S1 samples showed higher displacement value with 33.62 mm as compared to other two samples. Moreover, in type-III S2 samples displayed higher displacement with 34.12 mm.

From the present results it is clear that the maximum displacement was based on the percentage of the fibre content. When the dosage of fibre increased the maximum displacement was also increased. Also, the break load of composite specimens was higher at 4.5 KN in S2 samples of type-III as compared to type-I and II samples (figure 4). The break load and maximum displacement of double shear property was presented in table 5.

3.3. Delamination properties

The table displayed several characteristics, such as break load, total deformation, and ultimate delamination strength (7). In Type-I, better delamination properties in S1 samples (5.2 mm) as compared to S2 and S3 (figure 5(A)). In type-II, delamination properties were maximized in the S2 sample (3.8 mm) and significant

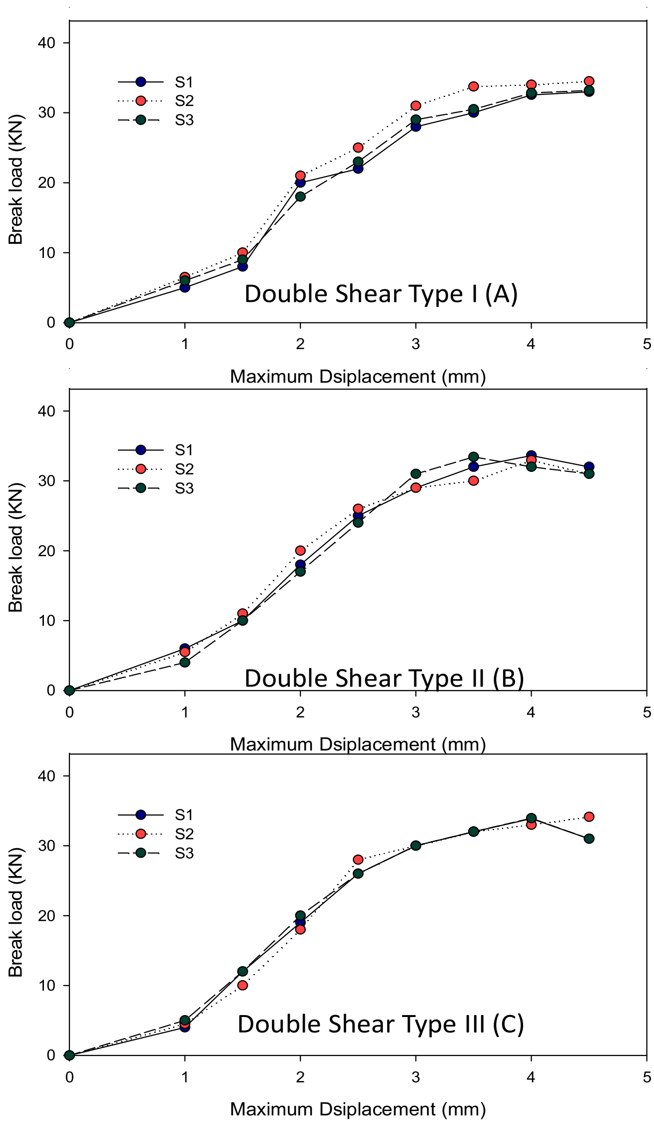

Figure 4. Result of double shear test.

Table 5. The distinct specimens' twin shear characteristics.

Composite samples	Break load (KN)	Displacement at break load (mm)	Maximum displacement (mm)
(TYPE -I)			
S1	3.88	3.52	32.55
S2	3.52	3.25	33.75
S3	3.74	3.84	32.82
(TYPE -II)			
S1	3.87	3.42	33.62
S2	3.92	3.89	32.94
S3	3.62	3.99	33.42
(TYPE -III)			
S1	3.89	3.85	33.89
S2	4.5	3.88	33.12
S3	3.99	3.89	34.94

with other treated samples (figure 5(B)). Correspondingly, Type-III exhibited higher displacement in S1 samples (2.9 mm) and all the samples treated were significant with each other (figure 5(C)). Table 6 shows the distinct specimens twin shear characteristics.

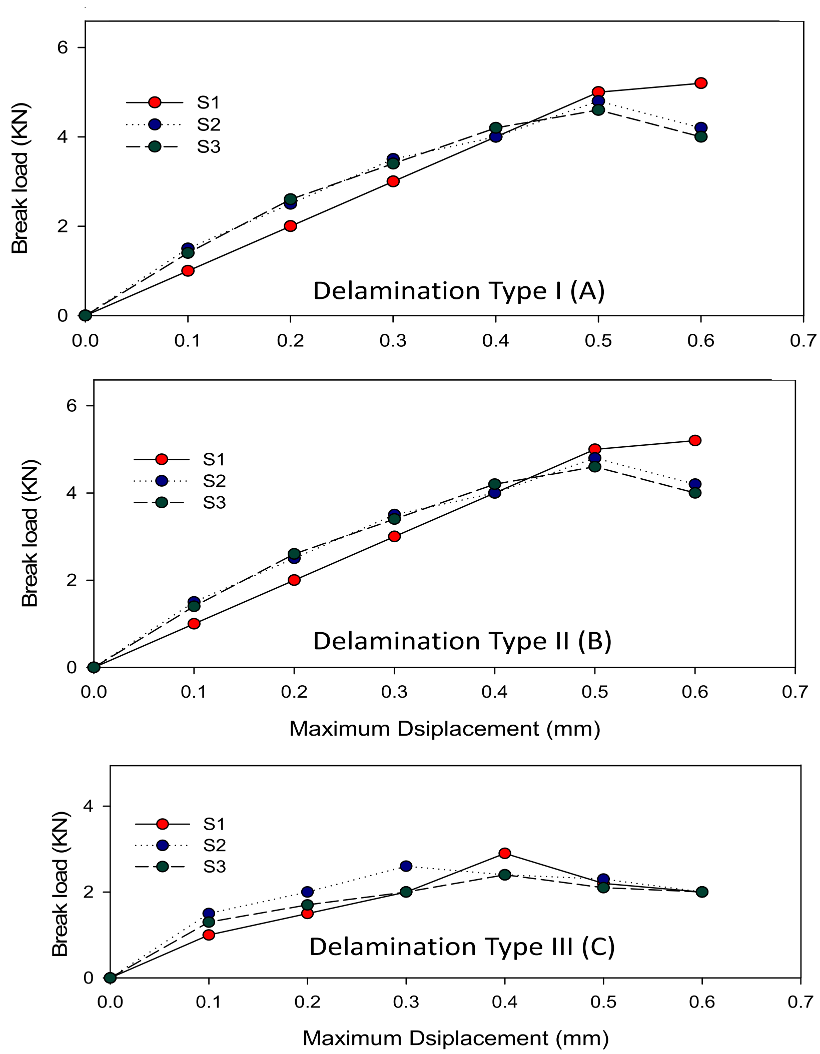

Figure 5. Result of delamination test.

In a group analysis, maximum delamination property was displayed in the type-I samples as compared to type-II and III (figures 5(A)–(C)). Similar to this, type-I samples showed more break load than the other two types. Overall, the results suggest that the maximum delamination properties are directly proportional to the concentration of the natural fibers. Previously, composition of the abaca fibers (75%) blended with jute (25%) showed superior delamination property [4].

3.4. Mechanical analysis in motion

3.4.1. Storage modulus (E')

The Effect of different types of natural fibres ratio in the storage module (E') of the bio-composites at the maximum frequency of 1 Hz. The storage module values were significant between the different natural fibres (figure 6(A)). The values were prominent for Type-II specimens at maximum temperature at 90.44 °C and it is significant with Type-I (89.58 °C) and Type-II (82.11 °C) respectively. The storage modulus curve also evidently displays that the integration of natural composites increases the E' values substantially. Our findings were similar to the previous research of kenaf/epoxy composites [15].

3.4.2. Loss modulus (E')

DMA curves of loss modulus showed that the Type-II samples reached maximum dissipation of mechanical energy (362.0 MPa) as compared to Type-I and Type-III composites with 335.02 MPa and 300.4 MPa respectively (figure 6(B)). As compared to storage modules (E') a similar trend was followed in the loss modulus plots. It is also clearly evident the loss modules results that the amalgamation of different types of biocomposite composition causes the expansion of the loss modulus peak percentage, owed to the upsurge in chain divisions. Similar trends were observed in the previous research in dynamic mechanical analysis in incorporation of different nano oil palm empty fruit bunch [15].

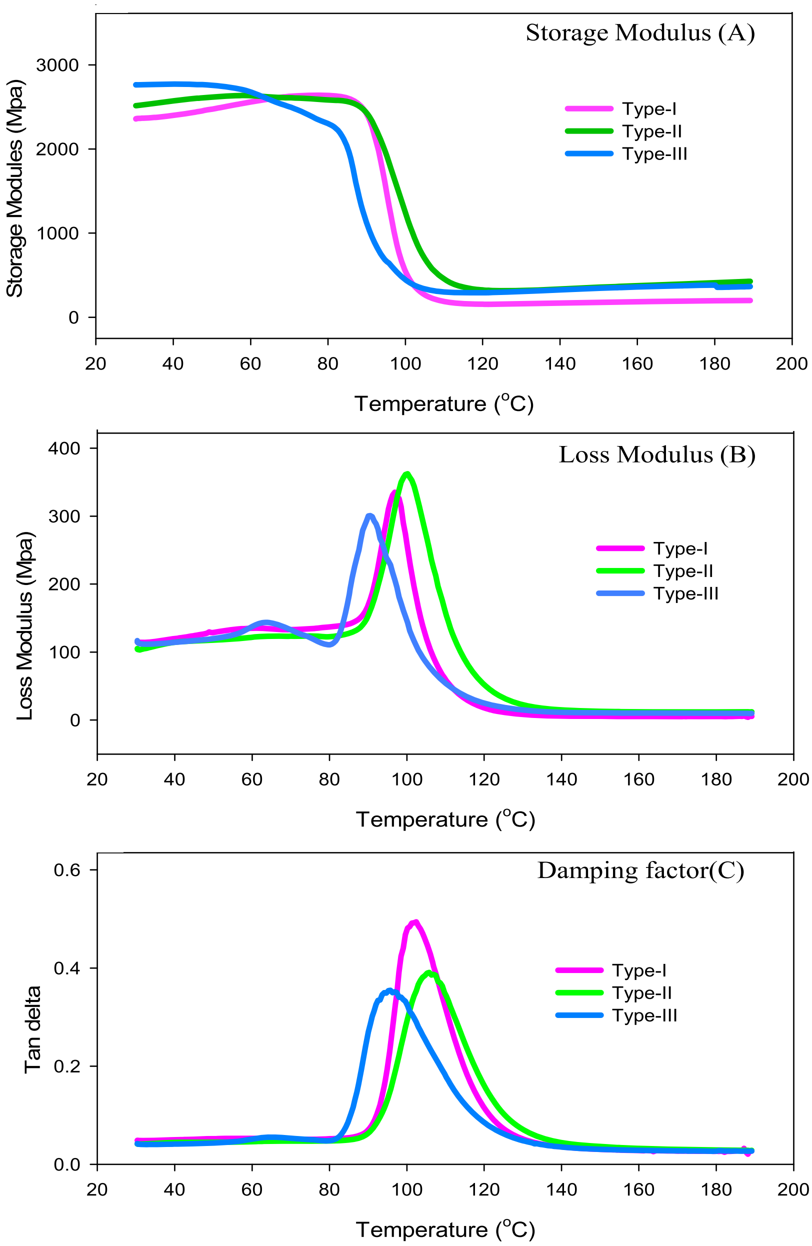

Figure 6. Result of dynamic mechanical analysis.

Table 6. The characteristics of each specimen's structural failure.

Composite samples	Break load (kN)	Displacement (mm)at break load	Maximum displacement (mm)
(TYPE -I)			
S1	0.62	2.8	5.2
S2	0.55	2.4	4.8
S3	0.52	2.7	4.6
(TYPE -II)			
S1	0.44	2.1	3.3
S2	0.52	2.6	3.8
S3	0.49	2.5	3.6
(TYPE -III)			
S1	0.38	1.9	2.9
S2	0.31	1.5	2.6
S3	0.36	1.7	2.4

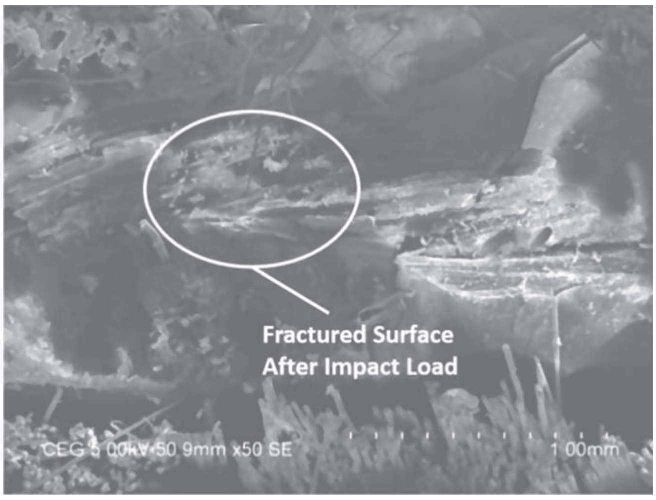

Figure 7. SEM picture of impact assessed type –I samples.

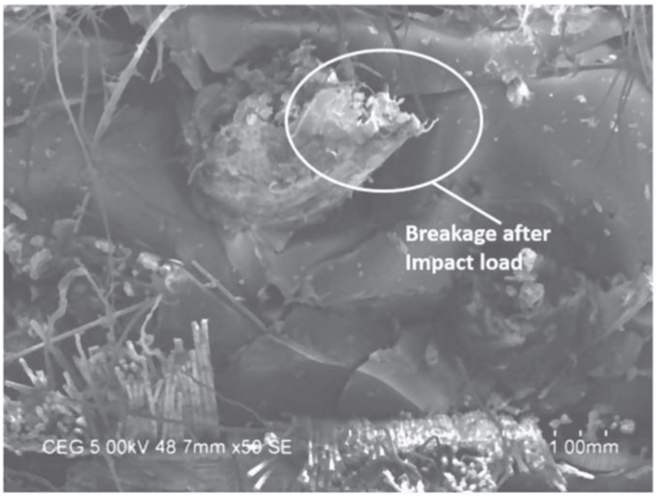

Figure 8. SEM picture of impact assessed type –II samples.

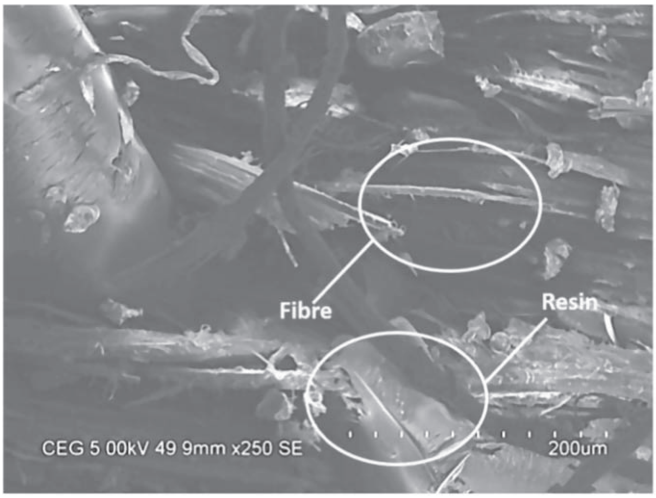

Figure 9. SEM picture of impact assessed type –III samples.

3.4.3. Tan delta

Damping results were studied based on the ratio of loss modulus E' and storage modulus E'. In general, Incorporation of natural fibres in a different composition ratio affects the behavior of damping in bio-composites; it is mainly due to shear stress dosages in the fibres combined with the viscoelastic energy indulgence in the natural fibre matrix. Similar to the above statement our results also provide better results in Type-I samples with significant peak area of 0.492 delivered at 102.01 °C as compared to Type-II (0.3907 at 105.56 °C) and Type-III (0.3540 at 96.36 °C) respectively (figure 6(C)).

3.5. Analyzing morphology with a SEM

The morphological investigation of bio-composite materials using SEM is carried out and presented (figures 7–9). The samples from the Type I, II, and III composite types impact tests were described.

The graphic clearly showed how each bio-composite fibre matrix (Kevlar, Palm, and Aloe Vera) was assembled internally figures 7–9. Following an impact load test, the fibres' linear breaking is depicted in figures 7 and 8. The bio-composite samples break apart at the breaking point with the impact of the samples [35–37]. Figure 9 also provides a closer look at the fibres and resins. The link between the fibre and resin shows no signs of breaking.

4. Conclusion

The natural fibre-reinforced hybrid composites were successfully fabricated using Vacuum-assisted compression moulding and Kevlar synthetic fibre. The effect of chemically treated aloe vera, bamboo and palmyra palm fibres are studied in detail for their mechanical and dynamic analysis property. The following conclusions have been drawn from the experimental investigation. In the impact test, the higher strength was obtained in type-1 in sample 10 Joule, type-2 in sample 2 at 8.3 Joule, and type-3 in sample 3 at 9.66 Joule. The remaining sample has the least shear strength. It is observed that the arrangement of fibre laminates has influenced the Impact strength of the composites. Typed one composites showed better impact strength than Alovera and palmyra fibres.

The inter-delamination test results show that the type sample one attains a maximum load of 2.8 kN. The Aloe vera and palmyra palm fibre composites withstand high load with small displacement due to the increased stiffness of the composites; therefore, palmyra palm fibre showed better wettability with the matrix and inter-lamina, hence resulting in maximum removal in type1 sample one S1 composites. In the double shear test, the higher strength was obtained in type-3 in sample 2 Joule, type-3 in sample 2 is 4.5 kN, type-3 in sample S2 is 4.5 kN, Reaming sample has the least shear strength. It is observed that the arrangement of fibre laminates has influenced the shear strength of the composites. Composite Type 3 sample 2 showed better shear strength than aloe vera and Palmyra fibres. The storage modulus of Type1 and sample S1 (Aloe vera & Palmyra palm) composites have higher stiffness and increased band strength with the epoxy resin. The composite type2 (bamboo & Aloe vera) showed the least storage modulus ascribed due to weak fibre-matrix adhesion and lower density of bamboo fibre. From the overall study, combining composite materials with natural fibres in a well-defined stacking sequence produced better mechanical and DMA properties. The composite type3 in sample3 (Aloe vera & palmyra palm fibre) showed better impact and double shear properties, i.e., the composite with natural fibres such as aloe vera and palmyra palm has better wettability with the matrix and synthetic fibre compared to bamboo fibre. The optimal hybrid composites were used to fabricate end-use components for automobile applications such as engine guards, silencer covers, roof panels, door panels, wipers, etc.

Acknowledgment

The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University (KKU) for funding this research through the Research Group Program Under the Grant Number: (R.G.P.2/453/44) and the authors thanks to Vel Tech Rangarajan Dr Sagunthala R&D Institute of Science and Technology to providing the necessary testing facilities for this research.

Declaration of interest

The authors declare no conflicts of interest regarding the research.

Data availability statement

Due to the ongoing development of an extended version of this study, the data cannot be made publicly available upon publication. The data that support the findings of this study are available upon reasonable request from the authors.

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