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RESEARCH ARTICLE

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A novel palm sheath and sugarcane bagasse fiber based hybrid composites for automotive applications: An experimental approach

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Abstract
A novel hybrid composite was developed from natural fibers and the mechanical properties were investigated in this work. The palm sheath and sugarcane bagasse fibres were the natural fibers used and epoxy resin was the matrix. By using compression-molding machine, various samples were prepared by varying the weight proportions of fibers. The performance of fibers was investigated under untreated and NaOH treated conditions. The tensile properties, flexural properties, hardness, and impact properties were evaluated using ASTM standards. The best sample was determined based on the experimental results. The best sample had the tensile strength of 19.80 ± 0.78 MPa, Young's Modulus of 0.953 ± 0.076 GPa, flexural strength of 28.79 MPa, impact strength of 2 kJ/m^2, and the hardness value of 38.02 HD. The best sample was used to develop an automobile dashboard to justify its application.

KEYWORDS
epoxy resin, mechanical characterization, micro-structural analysis, palm sheath fiber, sugarcane bagasse fiber

1 | INTRODUCTION

As the natural fibers have several benefits such as easy availability, biodegradability, lightweight, low cost and the ease of manufacturing, the natural fiber-based biocomposites have replaced the synthetic plastics in wide variety of fields [1]. Several researchers have proposed many natural fiber based composites for various engineering applications [2]. Because of their lightweight nature, biocomposites used by the automobile industries enhance their fuel economy [3]. Researchers have also investigated hybrid biocomposites that are made by adding two or more variety of natural fibers in a standard matrix to increase the mechanical properties [4]. Moreover, from the literature [5–8], it is confirmed that there is no reported study on the hybrid biocomposite based on palm sheath and sugarcane bagasse natural fibers. Therefore, in the present study, a hybrid biocomposite based on palm sheath and sugarcane Bagasse is developed for the automobile sector. The matrix material has considerable impact on the mechanical properties of the biocomposites. Hence, authors have used epoxy resin as the matrix material, due to its better reinforcement, high modulus, high strength, high chemical, electrical, heat resistance, and low shrinkage [9–11].

Earlier, Manikandan et al [12] developed unidirectional Palmyra fiber reinforced composites and estimated the mechanical properties. Dabade et al [13] studied the tensile properties of sun hemp and Palmyra fiber reinforced polyester composites. They evaluated their properties by changing the length of the fibers and weight ratio. Velmurugan and Manikandan [14] reported the mechanical properties of hybrid composites consisting of Palmyra and glass fibers. Reddy et al [15] evaluated the tensile properties of alkali treated Borassus fruit fine fibers. Balakrishna et al [16] addressed the consequence of process variables on the tensile strength of small and unsystematically oriented Palmyra fiber reinforced composites. They concluded that the tensile strength of the Palmyra fiber reinforced composite material was significantly affected by the time of alkaline treatment, length of fiber, and fiber volume fraction. The static and dynamic mechanical properties of palmyra palm leaf fiber treated in alkali and jute fiber reinforced in a polyester matrix were investigated by Shanmugam and Thiruchitrambalam [17]. They concluded that the addition of alkali treated Palmyra fiber boosted the impact strength of the composite. Sudhakara et al [18] considered the mechanical properties of Borassus fruit fiber and its composites using polypropylene. Neher et al [19] investigated the mechanical and physical properties of palm fiber reinforced acrylonitrile butadiene styrene composite. The mechanical properties of Palmyra fruit fiber and Palmyra fiber waste filled redmud was studied by Arumuga Prabu et al [20]. The outcome of surface treatment on the physical, chemical, and mechanical properties of palm tree leaf stalk fibers was addressed by Rout et al. [21].

Oladele [22] considered the influence of bagasse fiber reinforcement on the mechanical properties of polyester composites. Athijayamani et al [23] analyzed the mechanical properties of bagasse fiber-reinforced vinyl ester composites. Perdana and Hadi [24] investigated the mechanical properties of composite material based on waste materials from bagasse, eggshell, and styrofoam. Abdullah et al [25] studied the viscoelastic parameters and activation energies of the sugar cane bagasse powder reinforced epoxy resin composites. Balaji et al [26] examined the mechanical properties of short bagasse fiber reinforced cardanol-formaldehyde composites. The mechanical properties of polypropylene composites were improved using treated sugarcane fibers [27] and it was informed that the pre-treatment of sugarcane fibers would remove the impurities and improve the tensile modulus. Rachchh and Trivedi [28] investigated the mechanical and vibration properties of the hybrid composite plates made from E-glass and bagasse, and unsaturated polyester resin. They determined the values by both experimental techniques and using the finite element analysis method. Riyajan and Teprak [29] examined the effect of bagasse fiber and urea on a new type of biopolymer produced from gelatin and natural rubber. The mechanical and thermal properties of bagasse ash filled epoxy composites reinforced with hybrid plant fibers were studied by Vivek and Kanthavel [30]. Recently, Ramasubbu and Madasamy [31] fabricated a car bumper using sisal fiber composite, kenaf fiber composite, and hybrid composite.

2 | MATERIALS AND METHODS

The sugarcane bagasse is an abundant waste fibrous residue of sugarcane. The sugarcane bagasse was purchased from a sugarcane juice shop at Sivakasi, Tamil Nadu, India. Sugarcane bagasse from which the fiber was extracted is shown in Figure 1 (A). The palm sheath was collected from Sethur village (situated near Rajapalayam), Virudhunagar district of Tamil Nadu, India. The Palm sheath from which the fiber was extracted is shown in Figure 1(B). Polymer used is epoxy

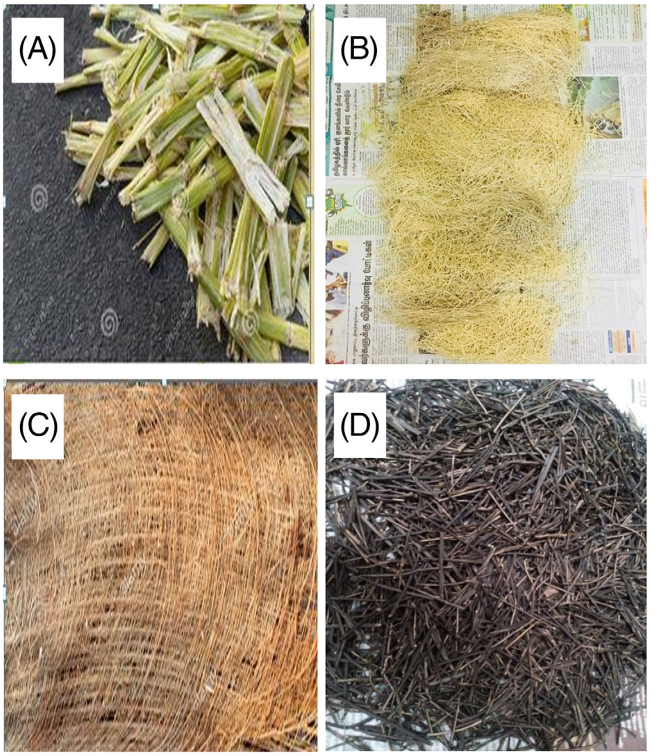

FIGURE 1 (A) Bagasse, (B) Bagasse fiber, (C) Palm sheath, and (d) Palm sheath fiber [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Properties of epoxy resin

Sl. No.	Characteristics	Values
1	Density (g/cm^3)	1.30
2	Tensile strength (MPa)	11
3	Elastic modulus (GPa)	0.15
4	Elongation at break (%)	1.7

resin (Araldite LY556) and it has a density of 1.3 g/cm^3. The hardener used is Aradur HY951 and these materials were procured from Covai Seenu Enterprises, Coimbatore, Tamil Nadu, India. Polyvinyl alcohol was the releasing agent used and it was supplied by MAAX SOLUTIONS INC., Coimbatore, Tamil Nadu, India.

2.1 | Extraction of bagasse fiber

The sugarcane bagasse was treated with distilled water for 10 days and the distilled water was replenished every day. After treating bagasse with water, impurities present in bagasse were removed; and after the immersion, the color of bagasse was changed from yellow to white. Then, the fiber from bagasse was extracted employing hand work. The extracted bagasse fiber is shown below in Figure 1(C).

2.2 | Extraction of palm sheathfiber

After collecting the palm sheath from a palm tree, the palm sheath was dried in the presence of sunlight for 3 days. After the drying process, palm sheath was cut down into small pieces with a size varying from 3 to 5 cm. The purpose of cutting down palm sheath into small pieces was to reduce the complexity in the alignment process. Extracted palm sheath is shown below in Figure 1(D).

2.3 | Chemical treatment of fibers

The fibers were chemically treated to increase upon the physical and mechanical properties [32,33]. Initially, the fibers were cleaned with distilled water. Then, 5% NaOH solution was transferred into the fibers, and it was agitated for 30 minutes at a temperature of 30°C.The liquor ratio of 20:1 was maintained. This would remove the hemicellulose, lignin, and other fatty materials. The alkali solution was drained out from the fiber and was washed with distilled water quite a few times to dispose of the additional alkali. The chemically treated fibers were dried in an oven at 108°C for 24 h [34].

2.4 | Epoxy resin

Epoxy resin was used as the matrix material in this work. The properties of the epoxy resin provided by the supplier are given in the Table 1.

2.5 | Sample preparation

Six different samples were prepared by changing the weight proportion of fiber and resin. Among the six samples, three were subjected to the alkaline treatment, while the remaining three were untreated. The fibers to matrix ratio were 60:40, 65:35, and 70:30. However, the weight ratio of the palm and bagasse fibers is kept being constant as 40:60. The weight of the matrix, palm fiber, and bagasse fiber are shown in Table 2.

The upper and lower portions of the dies were cleaned to remove the residual impurities already deposited in the die. The required weight of the resin and fibers were weighed using a weighing machine. The matrix and hardener were mixed with the ratio of 10:1 and the mixture was agitated by a stick. The hardener was added to increase the adhesive properties of the matrix. The weighed quantity of 50 mm length palmyra and bagasse fibers were well mixed and spread uniformly in the mold of 150 × 150 × 3 mm^{3}size and compressed by applying a load of 50 tons by hydraulic compression. The resin, accelerator, and catalyst were mixed and then poured over the compressed fiber mat, and the load is applied until the mold is closed completely. The samples were prepared and cured at room temperature. For each weight ratio, ten test samples were prepared by a compression molding machine. The average property values were considered. The test samples used for the tensile test, flexural test, and impact test before and after fracture is depicted in Figure 2.

2.6 | Tensile tests

The tensile test was used to evaluate the tensile strength of the composite samples. The samples were tested as per the standards of ASTM D 3039 M with the help of INSTRON-6025 model Universal Testing Machine at a crosshead speed of 2 mm per minute.

2.7 | Flexural tests

Flexural test was used to determine the flexural strength of the samples that is also known as modulus of rupture and it is the stress developed in a material just before

TABLE 2 The composition of different samples

Samples	Treated / untreated	Ratio of Matrix and fiber	Ratio of palm and Bagasse	Weight of matrix (in g)	Weight of palm fiber (in g)	Weight of Bagasse fiber (in g)
S1	Untreated	70:30	40:60	75.6	12.96	19.44
S2	Untreated	65:35	40:60	70.2	15.12	22.68
S3	Untreated	60:40	40:60	64.8	17.28	25.92
S4	Treated	70:30	40:60	75.6	12.96	19.44
S5	Treated	65:35	40:60	70.2	15.12	22.68
S6	Treated	60:40	40:60	64.8	17.28	25.92

FIGURE 2 Test samples before fracture for: (A) tensile test, (B) flexural test, and (C) impact test; after fracture for (D) tensile test, (E) flexural test, and (F) impact test [Color figure can be viewed at wileyonlinelibrary.com]

yield takes place. It is the maximum stress experienced within the material at the moment of yield. The test was conducted on the Bluehill INSTRON Universal Testing machine. The flexural test was conducted as per ASTM D790 standard. The samples were cut to the size of $120 \times 12 \times 3$ mm according to the standard. The cross-head speed was kept as 2 mm/min.

2.8 | Impact tests

Impact strength determines the ability of absorbent impact energy (toughness) before breaking. An INSTRON CEAST9050 impact-testing machine was used to perform the impact test. Impact tests were performed as per ASTM D256 standard. The size of the samples was $60 \times 12 \times 3$ mm^3 and the samples were provided with notch as per the standards.

2.9 | Hardness test

Hardness testing is to appraise a material's properties, such as strength, ductility, and wear resistance. The hardness test was conducted on all prepared samples by using shore D durometer hardness testing machine.

2.10 | SEM analysis

SEM is considered as a technique to analyze the surface morphology, interfacial adhesion, and fracture dynamics of various composites [35–46]. The surface morphology of the fractured samples of the tensile, flexural, and impact tests were examined and analyzed using through the scanning electron microscope (SEM) of JEOL JSM model 6390 with an acceleration voltage of 20 kV. Morphological properties of the fracture samples were cut and sputter with thin layer of Gold to make the surface conducting and well viewing to their morphological observation.

3 | RESULTS AND DISCUSSIONS

3.1 | Tensile tests

The tensile strength, tensile modulus, and percentage elongation values were calculated by conducting the tensile test and the results are presented in Table 3. The results indicated that the tensile strength is maximum at 19.80 MPa for the treated hybrid palm and Bagasse fiber composite samples of proportion 60:40 (S6). However, the untreated composite of same proportion (S3) had the tensile strength of 13.79 MPa, which is 43.58% lower than the treated composites. Besides that, the treated composite of proportion 65:35 (S5) exhibited the tensile strength of 12.10 MPa and the untreated fibers of same proportion (S2) had the tensile strength of 9.15 MPa. The treated and untreated composite samples of proportion 70:30 (S4 and

TABLE 3 Tensile properties of different composite samples

Samples designation	Tensile strength (MPa)	Young's modulus (GPa)	% Elongation
S1	6.45 ± 0.60	0.321 ± 0.076	8.12 ± 0.16
S2	9.75 ± 0.52	0.452 ± 0.082	11.76 ± 0.14
S3	13.79 ± 0.48	0.628 ± 0.086	15.12 ± 0.18
S4	7.90 ± 0.96	0.345 ± 0.084	8.32 ± 0.16
S5	12.10 ± 0.84	0.622 ± 0.078	11.17 ± 0.17
S6	19.80 ± 0.78	0.953 ± 0.076	15.73 ± 0.15

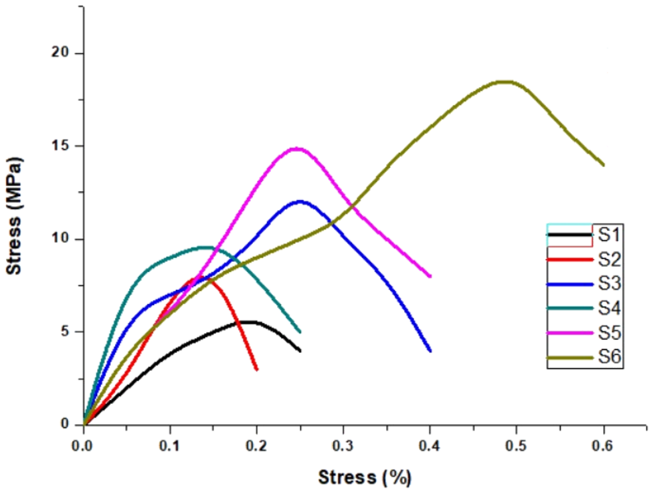

FIGURE 3 Stress–strain curves for the composite samples during tensile testing [Color figure can be viewed at wileyonlinelibrary.com]

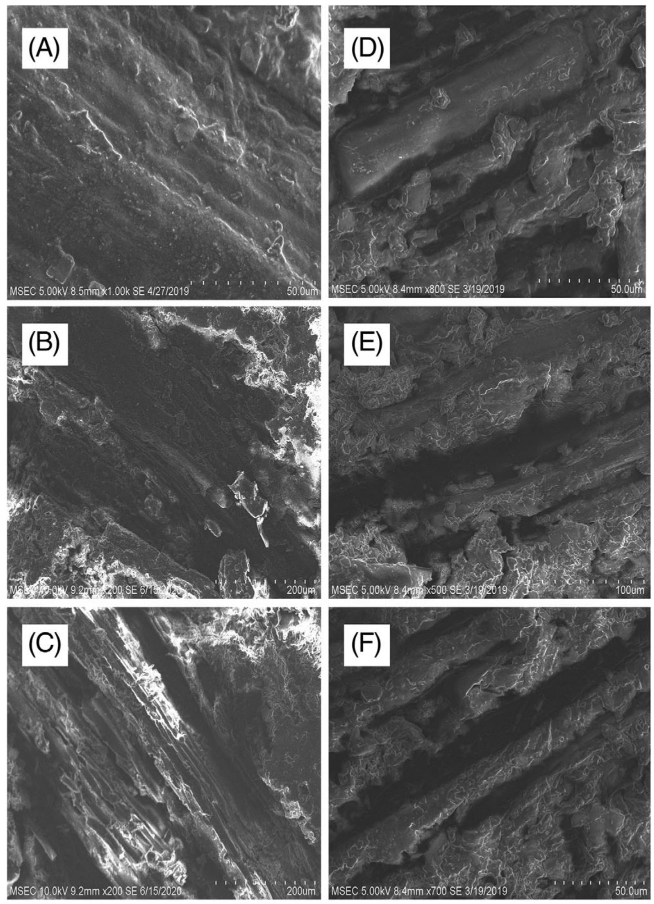

FIGURE 4 SEM images of tensile fracture of (A) Untreated 70:30, (B) Untreated 65:35, (C) Untreated 60:40, (D) treated 70:30, (E) treated 65:35, (F) treated 60:40 composites

S1) exhibited the tensile strength of 7.90 and 6.45 MPa respectively. The tensile strength of the treated composites was increased by more than 25% when compared to untreated composites for all the proportions due to the alkali treatment of fibers, which improves the adhesion between the fiber and matrix and simultaneously increases the tensile strength of the composites. The tensile strength of the best sample (S6) is 38.33% greater than that of Bagasse ash filled banana/flax biocomposites [30] and 41.63% greater than Red Banana Peduncle wood filler composites [42].

Similarly, the Young's modulus for the treated hybrid palm and Bagasse fiber composite of proportion 60:40 (S6) was maximum at 0.953 GPa which is 51.75% greater than the untreated composite of same proportion (S3) 0.628 GPa. Besides that, the treated composite of proportion 65:35 (S5) showed the Young's modulus of 0.622 GPa and the untreated fibers of same proportion (S2) had the Young's modulus of 0.452 GPa. The treated and untreated composite samples of proportion 70:30 (S4 and S1) exhibited the Young's modulus of 0.345 GPa and 0.321 GPa respectively. The Young's modulus of the treated composites was improved when compared to untreated composites for all the proportions due to the alkali treatment of fibers. The % elongation of the fiber composites of proportions 60:40 (S6), 65:35 (S5) and 70:30 (S4) are 15.73, 11.17, and 8.32 respectively and the corresponding values of untreated composites are 15.12, 11.76, and 8.32 respectively. The stress–train curves for the composite samples during tensile testing are shown in Figure 3.

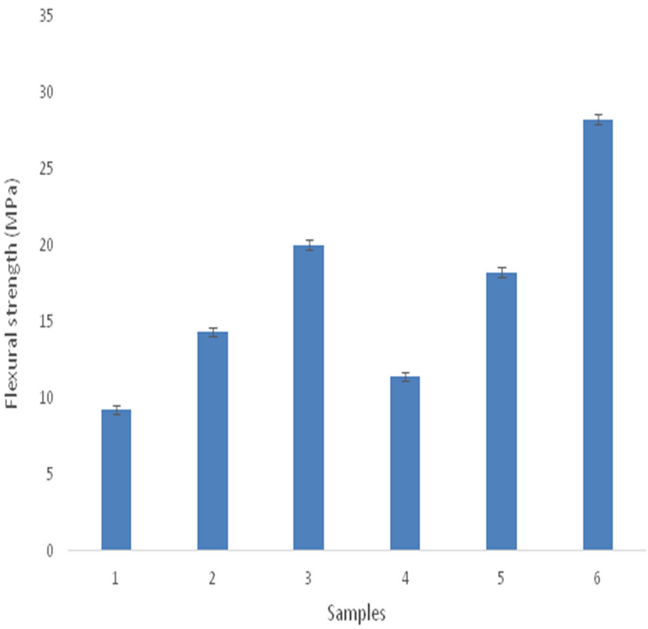

FIGURE 5 Flexural strength of composites [Color figure can be viewed at wileyonlinelibrary.com]

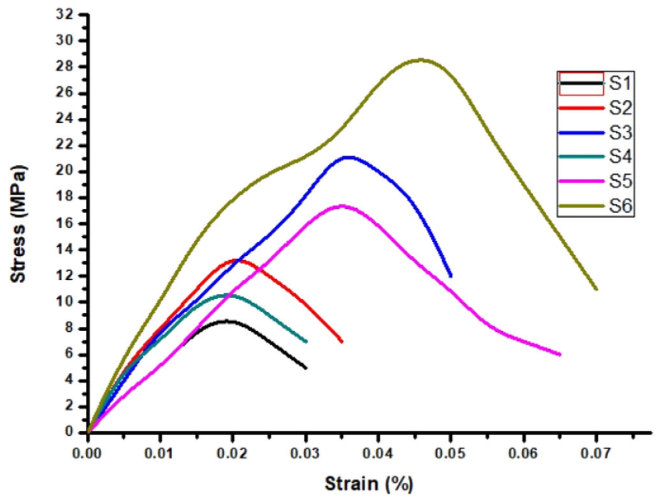

FIGURE 6 Stress–strain curves for the composite samples during flexural testing [Color figure can be viewed at wileyonlinelibrary.com]

SEM examined the surface topology of untreated and treated palm sheath and sugarcane bagasse fiber composites. The effect of the surface treatment on the interface between the palm sheath and sugarcane bagasse fiber was analyzed by examining the formation of a layer of ornate SEM ingredients. Figure 4 shows the SEM images of tensile fracture of (a) Untreated 70:30, (b) Untreated 65:35, (c) Untreated 60:40, (d) treated 70:30, (e) treated 65:35, (f) treated 60:40 palm sheath and sugarcane bagasse fiber composites. SEM images have confirmed that typical structural changes occur in the fiber surface. It confirmed that NaOH treatment has made the fiber surface harder, due to the partial removal of hemicellulose, lignin, and other soluble substances. Large and unequal voids were observed in the SEM images. It is possible to see that there are a lot of pulling strands and that the fiber surfaces are clean, indicating poor adhesion between the matrix and the fibers. NaOH treated fibers which showed that the top of the fibers had been altered therapeutically, and although the external features of the fibers were not clearly visible, it appears to be a more cohesive surface on its surface. From the figures, it is noted that the misalignment of fiber in the matrix and other voids in the composite leads to the appearance of a failure before the mechanical investigation is performed. Matrix plasticization and embrittlement observed affects the mechanical properties and dimensional stability where pressure distribution is not

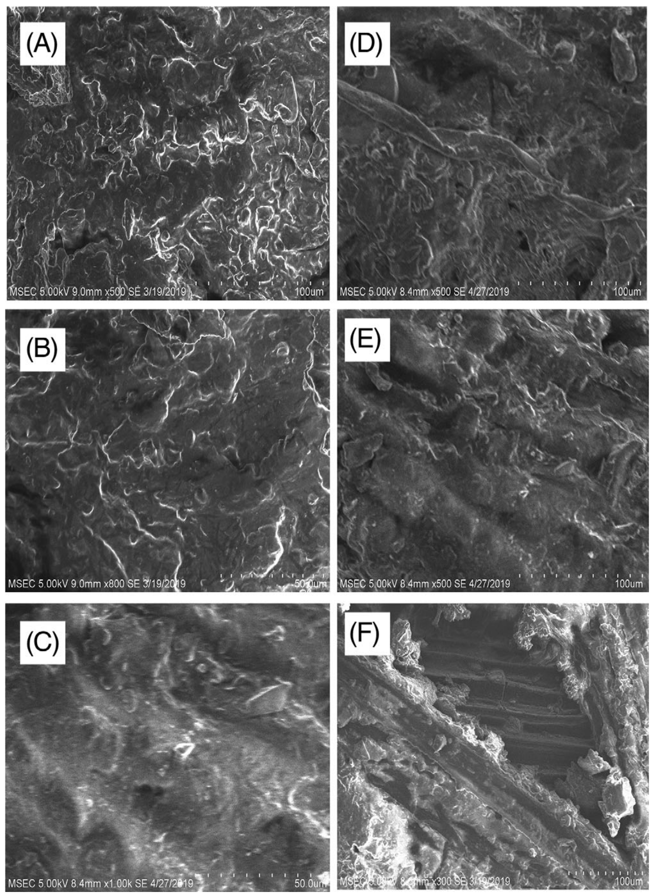

FIGURE 7 SEM images of flexural test fracture of (A) Untreated 70:30, (B) Untreated 65:35, (C) Untreated 60:40, (D) treated 70:30, (E) treated 65:35, (F) treated 60:40 composites

proper during the preparation of composites. Fracture of fibers is found to be at the visible region and the surface morphology is smooth and fuzzy.

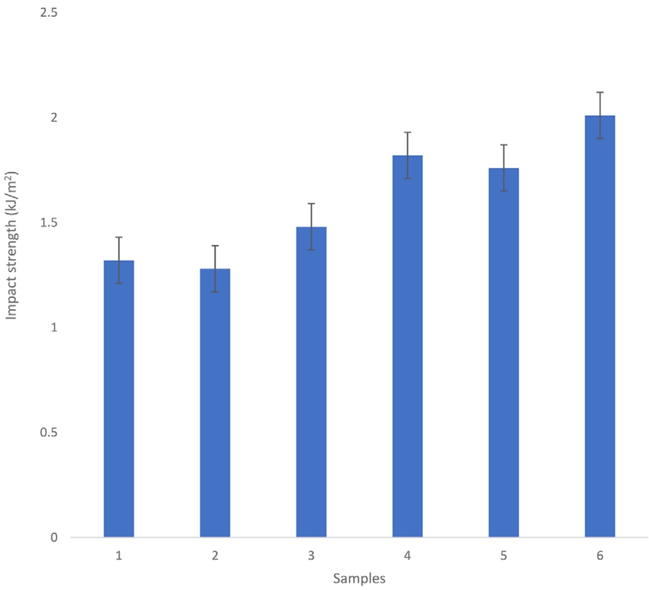

FIGURE 8 Impact strength of composites [Color figure can be viewed at wileyonlinelibrary.com]

3.2 | Flexural tests

The flexural strength is determined experimentally for treated and untreated composite samples and the results of the composite samples are shown in Figure 5. From the results, it is evident that the combination of treated palm and Bagasse fiber composite samples of proportion 60:40 (S6) exhibited the maximum flexural strength of 28.79 MPa than the other composite samples. However, the untreated composite of same proportion (S3) showed the flexural strength of 20.01 MPa, which is 43.90% lower than the treated composites. The treated hybrid composite samples of proportion 65:35 (S5) and 70:30 (S4) has given the flexural strength of 18.65 MPa and 10.21 MPa respectively and the untreated fibers of same proportion has the flexural strength of 14.01 MPa and 8.99 MPa respectively. From the results, it is seen that the solidification of the bond between the fiber and matrix was made by the alkaline treatment that increases the flexural strength of the composites. The flexural strength of the treated composites was increased by more than 30% compared to untreated composites for all the proportions. The flexural strength of the best sample (S6) is 15.07% greater than that of Bagasse ash filled banana/flax biocomposites [30] and greater than that of Red Banana Peduncle wood filler composites [42]. The stress–strain curves for the composite samples during flexural testing are shown in Figure 6.

Figure 7 shows the SEM images of the fractured interface of composite flexural samples of (A) untreated 70:30, (B) untreated 65:35, (C) untreated 60:40, (D) treated 70:30, (E) treated 65:35, (F) treated 60:40 palm sheath

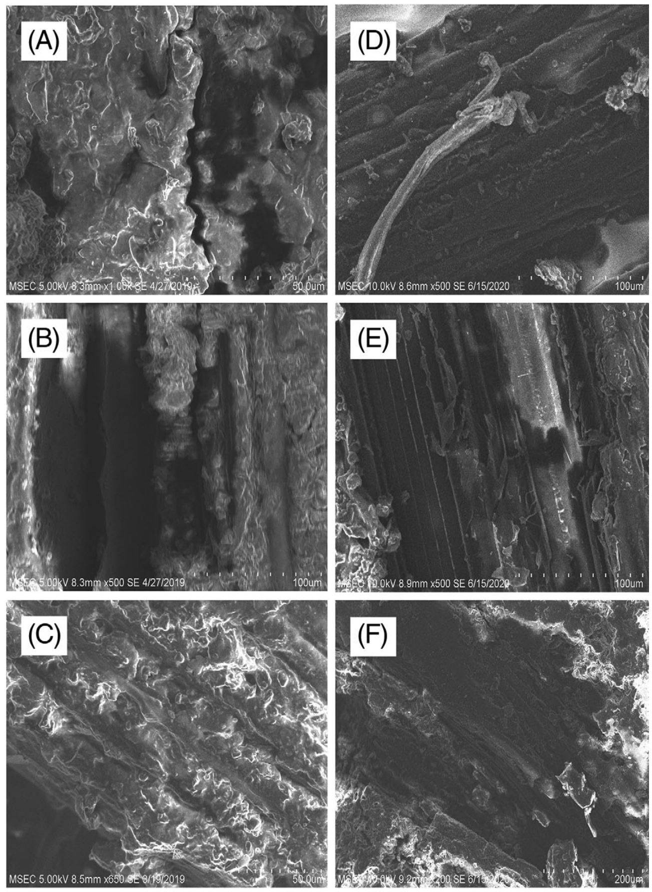

FIGURE 9 SEM images of impact test fracture of (A) Untreated 70:30, (B) Untreated 65:35, (C) Untreated 60:40, (D) treated 70:30, (E) treated 65:35, (F) treated 60:40 composites

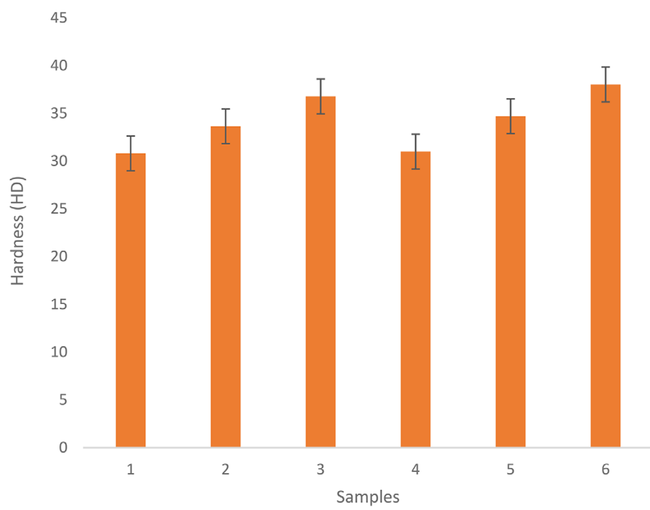

FIGURE 10 Hardness of composites [Color figure can be viewed at wileyonlinelibrary.com]

and sugarcane bagasse fiber composites. Compared to the fracture surface of the untreated composite, NaOH treated fiber composites are less sensitive and matrix

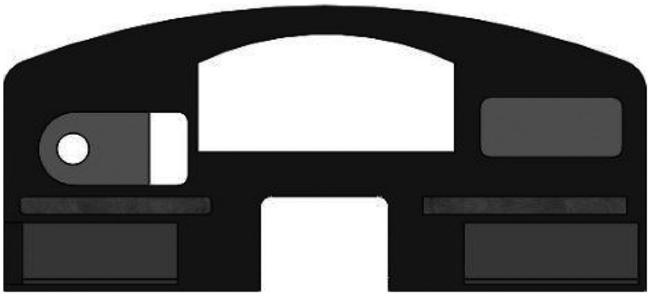

FIGURE 11 Solid works model for the dashboard

FIGURE 12 Fabricated dashboard model [Color figure can be viewed at wileyonlinelibrary.com]

particles are found to be more adherent. The figure also indicated the poor dispersion and voids. It can be seen from the figure that the fibers are further dispersed, and the fusion of the fiber and voids is reduced, which brings about better adhesion between the fiber and the visual matrix. It was evident from the figure that there was fiber extraction, fiber-matrix imbalance and matrix fragmentation and voids in the samples.

3.3 | Impact tests

The impact strength of these composites is shown in Figure 8. It is observed that the combination of treated palm and Bagasse fiber composite samples of proportion 60:40 (S6) showed a higher impact strength of 2 kJ/m^2 than other composites. At the same time, the untreated composite of same proportion (S3) had the impact strength of only 1.5 kJ/m^2. Then, other treated composites of proportion 70:30 (S4) provided an impact strength of 1.8 kJ/m^2, while the untreated fiber composite (S2) provided an impact strength of 1.4 kJ/m^2. Besides the treated and untreated fiber composite of proportion 65:35 indicated the impact strength of 1.75 kJ/m^2 and 1.35 kJ/m^2, respectively. It is concluded that the treated fiber composites provided a 33% increase in the impact strength than untreated fibers. The impact strength of the best sample (S6) is 5.7% greater than that of hybrid composite proposed in [31] and closer to Red Banana Peduncle wood filler composites [42].

Figure 9 shows the SEM images of the fractured interface of composite impact sample of (A) untreated 70:30, (B) untreated 65:35, (C) untreated 60:40, (D) treated 70:30, (E) treated 65:35, (F) treated 60:40 palm sheath and sugarcane bagasse fiber composites. The impact also indicated that the fibers are cut in the longitudinal direction, due to the applied load. From the observation, these SEM images showed that fiber ruptured, swelling fibers, creation of holes are certain forms of surfaces seen in the composites. The compatibility between the untreated fibers and epoxy matrices is poor, as evidenced by the presence of voids, aggregates, and pull-out fiber on the fracture edge, leading to its poor thermal and mechanical properties. On the other hand, alkali treated fibers showed the best interaction between the fibers and epoxy matrices. SEM images of the fracture surfaces of the composites indicating that the compatibility between the untreated fibers and epoxy matrices is also poor. The compatibility between the untreated fibers and epoxy matrices is poor, as proved by the presence of voids on the fracture surfaces. On the other hand, better adhesion between fibers and epoxy matrices has been found in the treated fibers by indicating that the interaction between fibers and epoxy matrices is improved when the fiber was treated by NaOH. This validates the results of thermal and mechanical analysis that the better adhesion of fiber/matrix increased the thermal and mechanical properties of the composites.

3.4 | Hardness test

The hardness values were determined for various composition of samples (both treated and untreated fibers) and are plotted in the Figure 10. From the results, it is noted that the treated palm and bagasse fiber composite samples of proportion 60:40 (S6) is 38.02 HD; whereas the untreated composite sample of same proportion (S3) is 36.78 HD. Thus, the hardness strength is improved by approximately 20% in treated samples than its untreated counterpart. Hardness strength of the other treated fibers is also provided in the same figure and showcases better hardness strength than the untreated fibers.

3.5 | Model making for dashboard

The dashboard of an automobile is an important part. The impact strength and hardness are the important properties required for dashboard. The model of the dashboard was developed using the SOLIDWORKS 2016 software, and the model is shown in Figure 11.

Since, hybrid composite sample of proportion 60:40 (S6) displayed better tensile, flexural, impact and hardness properties; therefore, the respective composition was considered to be the optimal composition for making the dashboard. The hand layup method was used to make the dashboard experimentally and the fabricated dashboard model is shown in Figure 12.

4 | CONCLUSION

The mechanical properties and microstructures of a natural fiber based hybrid composites were addressed in this paper. The hybrid composite was developed from the natural fibers and epoxy resin. Different test samples were prepared by varying the fractions. Various mechanical tests were conducted according to ASTM standards. The results showed that the effectiveness of the proposed composite. The optimum mix was used to produce a dashboard, an automobile part that would reduce the weight of the automobile considerably, and hence the fuel economy would be enhanced.

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CONFLICT OF INTEREST

The authors have no conflict of interest to report.

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