PHYSIO-MECHANICAL & WEAR PERFORMANCE OF BANANA FIBER/WALNUT POWDER BASED EPOXY COMPOSITES

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Abstract
The present environmental condition indicates the immediate need for sustainable materials containing mainly natural elements for composite fabrication. Encouragement of natural fibers in composite materials can significantly reduce the greenhouse effect and the high cost of manufacturing synthetic fiber-based polymer composites. Hence, this study aimed to investigate the physio-mechanical properties of banana fiber (BF) fiber - based epoxy (EP) composites filled with walnut shell powder (WNP). Fabrication was carried out by mixing and cold pressing with fixed BF proportion and varying percentages of WNP (0%, 5%, 10%, 15 wt. %). The results obtained in the study suggest the mechanical properties of the BF/EP composite were enhanced with the addition of WNP as a filler. This is because the WNP filler occupies the spaces in the composite, which bridge the gaps between the banana fibers and the epoxy matrix; also, the inclusion of walnut powder in the BF/EP composites greatly enhanced their wear resistance. The microstructural properties of the composites were examined by scanning electron microscopy (SEM).

Keywords
banana fibers; epoxy composites; walnut powder; mechanical properties; wear properties.

Introduction
In recognition of the growing concern over carbon emission and plastic waste, natural fibers in biopolymer matrices are gaining interest in the composite domain. Naturally occurring fibers have many advantages, including easy availability, biodegradability, low cost and good strength [1]. It is reported that natural fibers with polymer composites improve the mechanical properties more than the synthetic fiber-filled polymer composite but also the sustainability issue encouraged the researchers to expand their research on the use of natural fibers like BF, in the field of composite materials [2,3]. In addition to natural fibers, natural particulate fillers are also often used as reinforcement material to provide sufficient impact strength to the matrix materials [4–6]. To take advantage of two natural fibers materials (banana and coconut), hybrid composites (two fibers) are now being manufactured on a large scale [7]. The loading percentage of various fibers in the matrix may vary and depend on the fabrication process. The increase in banana fibers (BF) up to 30 wt.% with PP (polypropylene) enhances the mechanical properties [8,9]. Significant improvements in the mechanical strength were also obtained for BF

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and polylactic acid (PLA) composites at 40 wt.% of reinforcement [10]. Hybrid epoxy composites with jute and BF reinforcement at 50 wt.% exhibited better mechanical properties than the virgin epoxy [11]. Similar observations were reported by Venkateshwara et al. [12] in which they used 50% sisal fiber and 50% banana/epoxy composite in different percentages. The peroxide and permanganate-treated BF had higher properties than the untreated BF/EP composites [13].

The effect of variation of banana fiber length on the mechanical properties are studied and results showed that 10 mm fiber length and 15 wt.% fiber loading display the utmost magnitude of the tensile, hardness, flexural, and Impact strength [14,15]. The arrangement of the reinforcement in a plain-woven oriented hybrid composite of banana /kenaf fibers had higher strength than that of randomly twill oriented banana/Kenaf fiber [16]. Studies suggested that when only BF and EP are taken at 50/50 volume fraction, the product can sustain more load compared to other proportions. However, as we mentioned earlier, the mechanical strength of the fabricated composite depends not only on the volume fraction of fiber but also on the sample thickness and fiber weaving pattern. When BF was taken with polyester resin in different volume fractions 5%, 10%, 15%, 17.5%, and 20%, by different thicknesses of the composite (3mm and 5 mm). The results revealed that the 5 mm thickness has the optimum tensile, flexural, and impact strength value. Besides, plain woven fiber has always been stronger than randomly oriented fibers. By adding filler particles, the proportion of fiber content can be reduced, and the desired properties can be obtained. Because of this, most researchers have achieved their best results with 30wt% BF loading with epoxy composites filled with a particulate filler [17–19].

Hybrid polymer composites containing BF have also been characterized for wear performance. A jute-banana-epoxy composite, for instance, showed better wear performance than virgin epoxy [20]. Research has also been carried out on BF reinforced polyester resin for structural applications and it was found that BF with polyester resin exhibited improved strength than other natural fibers that can be employed for structural use. The BF composite properties have also been analyzed for load and length and it was shown that 30 mm fiber length gave the optimum mechanical and structural strength at 40 % BF loading. The study of the water absorption by BF composites reveals that the high-water absorption ability of BF results in lower mechanical properties [21,22].

The addition of natural fiber waste results in the enhancement of mechanical properties [23]. It is suggested that walnut shell powder (WNP), usually obtained in the form of waste materials, because of its unique physical and chemical properties has a huge potential to bring a substantial improvement to the properties of polymer composites. WNP, coconut shell, and rice husk have been added to prepare hybrid composites. The results have shown that hybridization remarkably improved the mechanical properties compared to single filler composites of one of the above three fillers [24]. In his investigation, Emel Kuram [25] used Powdered hazelnut and walnut shells as natural filler with ABS to develop hybrid polymer composites. With a single natural filler, the walnut shell flour was found to be usable for enhancing strengths (tensile, flexural and impact) and modulus. Similarly, the mechanical and tribological properties of the Walnut Shell Powder - Polypropylene natural composite have been investigated by Moustafa, N. M et.al. [26] and found out that by increasing the walnut shell powder content by 20% wt, the ultimate tensile and bending stresses are reduced by 19.5 percent, and the modulus of elasticity is reduced by 7.7%. P.Dhiman used natural jute, basalt fibre, and walnut shell to create the hybrid polymer composites. Composites with and without walnut shell filler were compared in terms of various characteristics and concluded that composites filled with walnut shell filler demonstrated better mechanical properties [27]. HDPE (High - Density Polyethylene) based composites filled with WNP and reinforced with bast fibers were investigated for their mechanical and wear properties, it was reported that the maximum strength was obtained at 40 wt. % of WNP in HDPE in the composite [28]. The effect of WNP on the physical - mechanical properties of polypropylene composites and MAPP (maleic anhydride grafted polypropylene) matrix composites have reported an increase in the mechanical properties [29].

Chemical treatment of natural fibers escalates the compatibility of fiber and matrix [13] by reducing the moisture absorption capability. The inclusion of natural filler in a conventional composite can boost the strength at a relatively low cost of composite. Alkali treated walnut shell powder is considered a helpful reinforcement material in epoxy matrix based composite by Singh, A. K. et al. [30]. He investigated that the properties of treated composites like tensile, compressive, and flexural strength increase up to 15% by weight and then start to decrease. The present work describes the physico - mechanical characterization of alkali-treated BF /WNP / EP composites. The composites were fabricated via mixing and cold pressing with varying weight percentages of WNP (0, 5, 10, and 15 wt. %), while the BF content was kept constant at 30 wt.%. The BF contents are kept constant to take advantage of the WNP filler in the composite, and the BF percentage is determined from previous literature reviews [9,19,31].

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Methods

Material: Matrix

Epoxy resin of grade LY-556 (Density 1.15 - 1.20 g/cm^3) with hardener HY- 951 was procured from Seema Corp., India. Hy-951 is an unfilled epoxy casting resin system hardener, having low viscosity with additional high filler possibility and can cure epoxy at room temperature.

Fiber Surface Treatment

The BF mats were treated to remove hydroxyl groups from the surface of the fibers with a 5 % alkali solution (NaOH) and enhance the fiber's adhesiveness with matrix. Obviously, hydroxyl groups are very sensitive to many reagents and increase the solubility of organic compounds in water. The fibers were dipped in the NaOH solution for 8 hours and then washed thoroughly with water. After washing, the fibers were dried in sunlight for 24 hours. SEM images of the Banana Fiber (BF) samples, treated BF and WNP are shown in Figure 1 (a, b, and c), respectively.

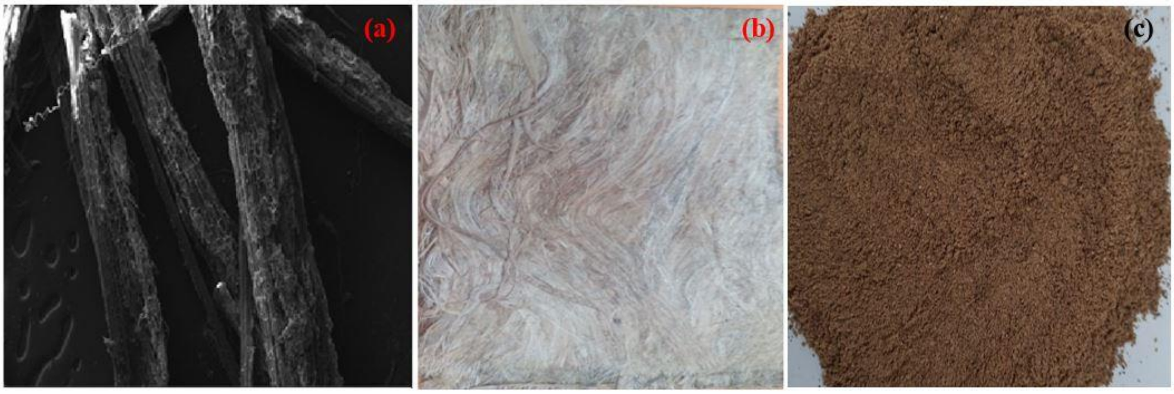

Figure 1. (a) SEM image of the banana fibers (b) Pictorial view of the NaOH treated banana fibers (c) pictorial view of the walnut powder.

Composite fabrication

The fabrication process adopted in the present investigation is shown schematically in Figure 2. A metallic mold with a 300 x 300 x 4 mm^3 cavity was prepared and the surface plates were machined to smoothen their surfaces. WNP and EP were mixed in a beaker and stirred by a mechanical stirrer for 15 minutes to homogenize the mixture. The treated, randomly oriented banana fiber mat was placed over the mylar sheet placed in the mold.

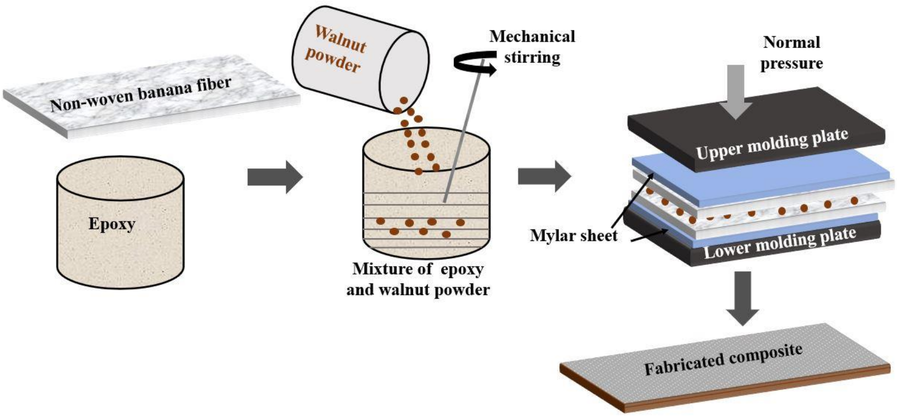

Figure 2. Fabrication process.

A mixture of EP and WNP was poured over a non-woven BF mat of thickness 2 mm. A second mylar sheet was placed to avoid sticking the composite to the molding plate. The composition was then pressed at a normal load of 147N and left to cure for 24 hours.

Table 1. Designation and detailed composition.

Designation	Composition (wt. %)		
	Epoxy resin (With Hardener)	**Banana fiber**	**Walnut powder**
BW1	70	30	0
BW2	65	30	5
BW3	60	30	10
BW4	55	30	15

Here BW1, BW2, BW3, and BW4 represent the compositions of the samples of BF at 30 wt. % and four wt.% of Wall-nut powder and epoxy

Characterization of the composite

Physical characterization.

The expression for the theoretical density (ρth) of composite material in terms of the weight fractions of the different constituents was that described by Agarwal and Broutman [32], as shown in equation 1 where ρe ρb ρwn are the densities of EP, BF, and WNP, while W represents the weight fraction of the same. The experimental densities (ρexh) of the composite have been determined by the Archimedes principle. The void fraction content (Vc) in the composites was calculated by using equation 2.

(1)
$$\rho_{th} = \frac{1}{\frac{W_e}{\rho_e}+\frac{W_b}{\rho_b}+\frac{W_{wn}}{\rho_{wn}}}$$

(2)
$$Vc = (\rho_{th} - \rho_{Exp}) \times 100/ (\rho_{th})$$

Water absorption percentage was measured by the difference of weight before and after immersion of the specimen for 10 days and then divided by the dry weight.

Mechanical characterization.

The test for hardness was carried out on a VICKERS Cum BRINELL (BV 50) Testing Machine supplied by Rockwell Testing Aids, New Delhi. Specimens of dog bone shape were cut from 4 mm thick molded sheets for the tests. The flexural strength was determined by a 3-point bending method according to the ASTM D-790 standard.

Wear Characterization.

A pin on the disc machine (DUCOM Instrument Pvt. Ltd, India) was used to determine the wear properties of the composites as per ASTM 99 [32]. The specific wear rate (SWR) was calculated relative to variations of the following factors; fiber content, sliding distance, sliding velocity, and normal load. The experiment disk was hardened, ground steel, whose hardness was 72 HRC and roughness 0.6µRa.The specific wear rate (SWR) was calculated by

(3)
$$\mathrm{SWR} = \frac{\Delta w}{\rho D f_n}$$

Where SWR is the specific wear rate, Δw (grams) is the total weight loss, ρ(g/cm^3) is the density, D(meters) is the sliding distance and fn (Newton) is the normal load. The control factors, as stated in Table 2, were studied in four levels. The level of control and selected control factor are shown in Table 2.

As per the goal of the experiment. S/N ratio was calculated from the different 16 level results. As minimum wear is required, a lower S/N as better was taken and computed by equation 4 [28].

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(4) $$S/N\ rati = -10\ xlog \frac{1}{16} \sum \mathrm{OD}^2$$

where S/N is signal to noise ratio, 16 = observation count, and OD = observed data. The calculation of the S/N ratio is given in eq. 4.
In a response table, the ranks assist you rapidly understand which factors have the greatest impact. The factor with the biggest delta value is ranked first, followed by the factor with the second largest delta, and so on [33].

Table 2. Control factors and their levels, as used in the experiments.

Control factor	Description	Level I	Level II	Level III	Level IV
1	WNP content (wt.%)	0	5	10	15
2	Sliding velocity (m/s)	1.5	2.5	3.5	4.5
3	Normal load (N)	15	20	25	30
4	Sliding distance (m)	800	1300	1800	2300

Results and Discussion

Effect of WNP filler loading on the void fraction of the composites

Table 3 shows the effect of WNP loading on the density and void fraction of the composites. The results indicated that increasing the walnut loading decreased both the theoretical and experimental density. The experimental density decreased from 0.95 kg/m^3 to 0.814 kg/m^3 while the theoretical density decreased from 0.902 kg/m^3 to 0.742 kg/m^3, which increases the void fraction based on the amplified difference in the experiment and theoretical density. The formation of void content might be due to the structure discontinuities created by increasing the filler loading. WNP has the lower density compared to epoxy resin and banana fiber and an increased percentage in the composition. The manufacturing and curing process disturbs the void fraction effectively.The void fraction has a significant impact on the mechanical properties, as shown in table 3.

Table 3. Effect of walnut shell loading on the void fraction on of the composites.

Designation	Theoretical Density (ρth) kg/m^3	Experimental Density (ρexp) kg/m^3	Void Fraction (%)
BW1	0.950	0.902	4.8
BW2	0.899	0.849	5.5
BW3	0.854	0.801	6.2
BW4	0.814	0.742	8.8

Effect of WNP filler loading on tensile strength and modulus of the composites

The effect of WNP content on the tensile strength of the banana fiber reinforced epoxy composite is shown in Figure 3. The increase in the WNP addition leads to enhancement of the tensile strength as well as the modulus of the composites. The peak tensile strength is reported to be 76.7 MPa at 15 wt. % WNP loading. At 0 wt. % filler loading, the tensile strength was 65.6 MPa which increased to 69.4 MPa at 5 % filler addition. The tensile strength further increased at 10 wt. % filler loading to be 74.1 MPa. The highest tensile modulus achieved is about 3.4 GPa at 15wt% of WNP loading. At 0wt% of WNP, the tensile modulus was 2.4 GPa which increased by 16% for 5 wt.% of WNP loading to 2.9 GPa. It was further increased by 13.3% at 10 wt.% walnut loading to 3.3 GPa.

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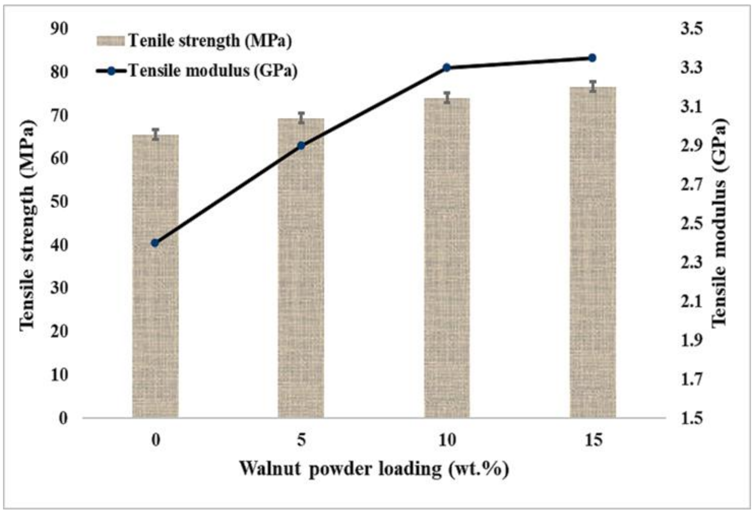

Figure 3. Effect of WNP filler Loading on tensile strength and modulus of the Composites.

An effective stress transfer due to the bonding of the WNP with the EP matrix we suggest is the reason for the improvement of the tensile strength. The WNP filler occupies the spaces in the composite which bridge the gaps between the banana fibers and the epoxy matrix. Initially, WNP is bound with BF (up to 10 wt. % of WNP as per our experiment) so it is increasing the tensile strength and after that, it crosses its optimum wt. % so it will not help to increase the tensile strength [34]. This shows that, with a growing content of walnut shell particles, there was an increase in the tensile strength and tensile modulus and peak value of tensile strength and modulus for 15 percent of walnut particles. This was attributed to the increased percentage of WNP increasing the adhesion and interfacial contact, which will increase the modulus and tensile strength up to optimum wt. % of WNP, after that it will reduce the adhesion and interfacial contact. The increase in the tensile modulus (Because of the increase in adhesion and interfacial bonding) with walnut filler is another reason for the improvement in the tensile strength.

Effect of WNP filler loading on the flexural strength and flexural modulus of the composites

BF reinforced composite flexural strength was observed to be 38.1 MPA and it increased with increasing WNP addition (Figure 4). At 5 wt.% of WNP loading, the flexural strength increased by 5.8 % to 40.2 MPa. The flexural strength further increased to 41.8 MPa with 10 wt.% WNP filler addition and was found to be maximum (43.2 MPa) at 15 wt. % loading, as in Figure 4. The WNP filler in the BF/EP composite imparted rigidity which enhanced the composite stiffness and resulted in improved flexural strength. It is possible that the increased flexural strength can be attributed to the addition of WN filler, which creates a more uniform mixture. A similar result was obtained by Rahman et al., and they bring that the weight percentage of fiber and filler material (both BF and any suitable natural filler material) is very important in determining the properties of composites [35]. The flexural modulus of our composites also increased with increased WNP addition. The maximum modulus was 2.5 GPa at 15 wt. % WNP loading. At 0 wt. % filler loading, the flexural modulus was 1.7 GPa which increased to 2.1 GPa at 5 % filler addition. The flexural modulus further increased at 10 wt. % filler loading, to 2.4GPa.

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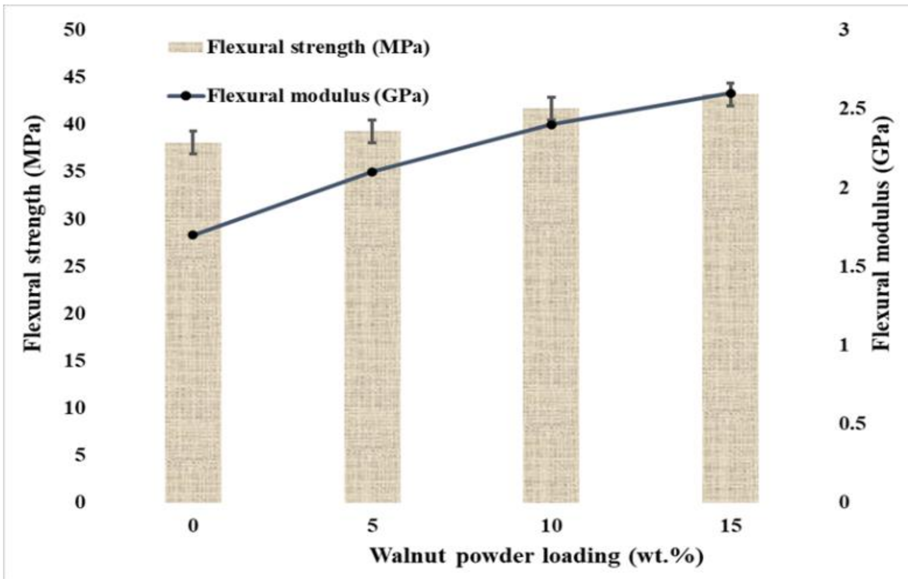

Figure 4. Effect of WNP loading on the flexural strength and modulus of the composites.

Effect of WNP filler loading on the impact energy of the composites

The effect of WNP filler loading on the impact energy of the BF/EP composite is shown in Figure 5. A similar trend was observed for the impact energy as for the tensile and flexural strengths shown in Figures 3 and 4, but much larger increases. Figure 5 indicates that the WNP filler loading in the BF/EP composites greatly improved the impact energy. The maximum impact energy was observed at 15 wt. % WNP loading and the minimum at 0 wt. % WNP loading, the impact energy for wt. 15% WNP loading increased by 25% compared to 10wt% loading. TheWNP filler addition thus, improving both the stiffness and strength and thus resulted in higher load-carrying capacity. The percentage increase in impact strength was higher at lower filler loading i.e., loading from 0 to 5wt%, but it gradually decreased as the WNP filler percentage in the composite increased. This suggested that adding WNP wt. % in the BF/EP composites at higher loadings may lead either to only a small change in the impact energy but had a more significant effect than on the TS and FS.

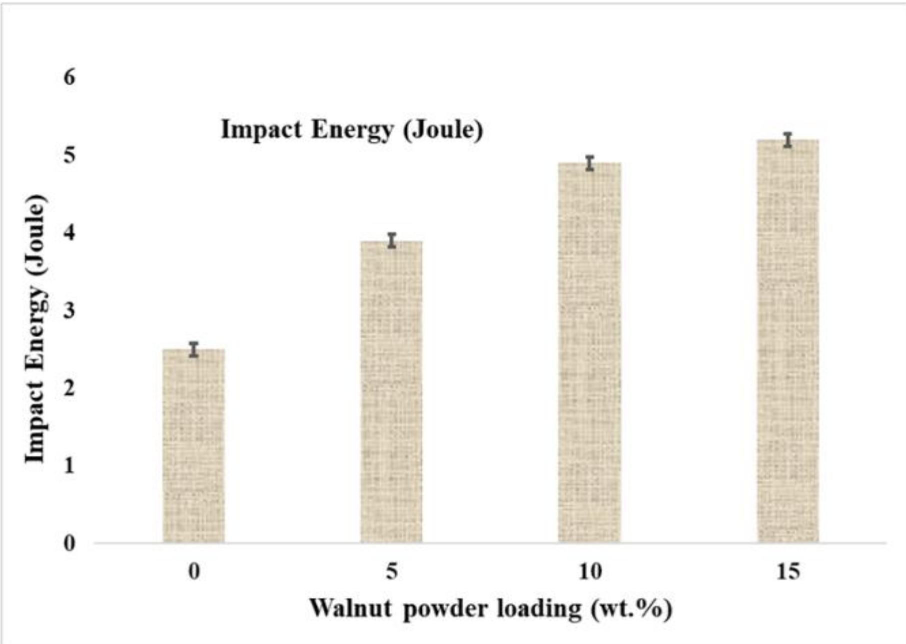

Figure 5. Effect of WN filler Loading on the Impact energy of the Composites.

Effect of WNP filler loading on the hardness of the composites

The effect of WNP filler loading on the hardness of the BF/EP composites in Figure 6. The hardness is defined as the resistance to indentation and as the WNP filler loading increased in the composites, the hardness of the composite slightly increased. The light dense particles of the WNP filler, which gathered at the surfaces upon cooling, made the surface hard compared to BF/EP composite. When more WNP filler was added to the composite, more filler accumulated at the surfaces causing the hardness to be slightly enhanced. The highest hardness was obtained at 15 wt. % WNP filler, 50.7 Hv, and the lowest was observed for 0 wt. % WNP filler, 42.8 Hv.

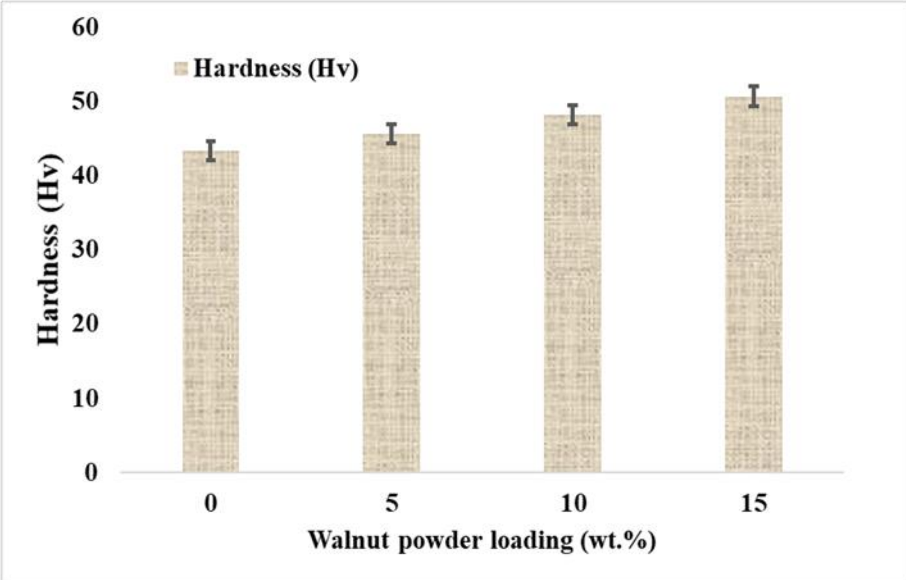

Figure 6. Effect of WNP filler loading on the hardness of the composites.

Taguchi analysis of the wear of the WNP filler loaded BF/ EP composites

The Taguchi method was used for the wear test. The four composite's specific wear rates for all 16 test runs and their corresponding S/N ratio are given in Table 4. The maximum specific wear rate was found to be a value of 9.93x10-8mm^3/Nm for the BW1 composite at 3.5 m/s velocities, 30 N load, and 1800 m distance. The minimum specific wear rate was observed as 3.25x10-8mm3/Nm for 5wt. % of walnut powder (BW2) at 1.5 m/s sliding velocities, 20 N load, and 1300 m distance. Similar findings were also shown by Kumar S. et al. [36] for specific wear rates for a similar sample. Table 4 also shows that all samples S/N ratios were between 140.061 and 149.762 dB (Decibels). The database effect of the SN ratio, which is shown in Table 4 is plotted in Figure 7. In Table 6 the most critical control factor was the sliding velocity followed by the fiber content, while the normal load showed the least effect on the specific wear rate. From Response Table 5, the best composition of control parameter that would produce the minimum wear was fiber content at level – II (5wt%) and sliding velocity at the level I (1.5 m/s), normal load at level II (15N),and sliding distance at level I (1800 m). The observations also revealed that increasing the WNP content from 5 wt. % to 10 wt. % increased the S/N ratio but a WNP loading of 15 wt. % decreased the S/N ratio which indicated a high specific wear rate. Table 5 shows the composite response table for the S/N ratio. The delta value was calculated by subtracting the maximum and minimum S/N ratio values, and the control factor was ranked using the delta value. The greatest delta value indicates a stronger influence on the specific sliding wear rate. The wear rate on the sliding condition was shown to decrease with increases in WNP content up to 10% but increased after that. This could be because filler particles function as a barrier between the rotating disc and the composite material, preventing wear. It can also be seen in Figure 7 about normal load, it can be concluded that the load increasing, initially decreases the rate of wear, because of a fixed amount of banana fiber in the new sample of WNP particulates.

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Table 4. Experimental design for the wear using L16 orthogonal array.

SL. No	Sliding velocity (m/s)	Walnut content (wt.%)	Normal load (Newton)	Sliding distance (m)	Specific wear rate (mm3/Nm)	S/N ratio (db)
1	1.5	0	15	800	6.21E-08	144.138
2	1.5	5	20	1300	3.25E-08	149.762
3	1.5	10	25	1800	4.29E-08	147.351
4	1.5	15	30	2300	5.74E-08	144.822
5	2.5	0	20	1800	7.41E-08	142.604
6	2.5	5	15	2300	6.35E-08	143.945
7	2.5	10	30	800	3.44E-08	149.269
8	2.5	15	25	1300	9.31E-08	140.621
9	3.5	0	25	2300	6.11E-08	144.279
10	3.5	5	30	1800	9.93E-08	140.061
11	3.5	10	15	1300	7.51E-08	142.487
12	3.5	15	20	800	6.75E-08	143.414
13	4.5	0	30	1300	5.73E-08	144.837
14	4.5	5	25	800	4.04E-08	147.872
15	4.5	10	20	2300	3.85E-08	148.291
16	4.5	15	15	1800	7.29E-08	142.745

Actually, there were two general regions of variation of wear against sliding velocity. The first occurred in the high-velocity region and the second in the low-velocity region. In the low-velocity region, the specific rate of wear is inversely proportional to the sliding velocity but in the high-velocity region, but increases with increasing velocity for solid/solid content but decreases for solid /liquid form content [37]. From Figure 7. However, while increasing the load, normal load initially reduces the wear rate because of the availability of a fixed amount of banana fiber and WNP particulates. However, once the ideal circumstances are achieved, the wear rate increases as the load increases due to an increase in contact pressure.

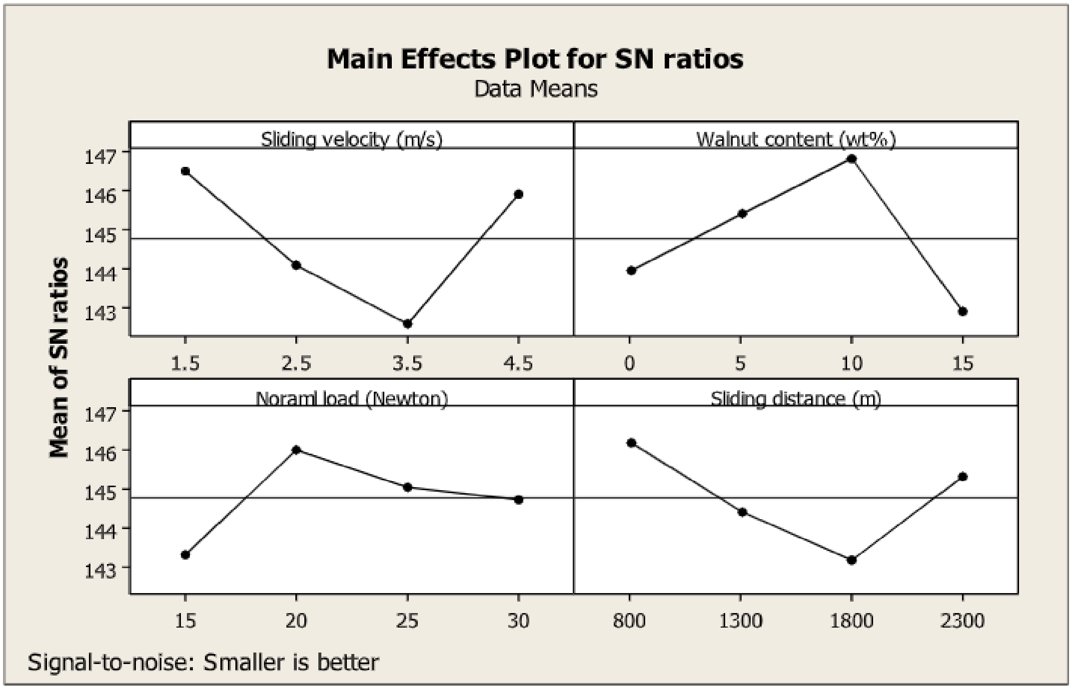

Figure 7. Effect of control factors on the specific wear rate of the composites.

Table 5. Response Table for Signal to Noise Ratio Smaller is Better.

Control Factors (All are in S/N ratio)				
Level	**Sliding velocity**	**Normal load**	**Walnut content**	**Sliding distance**
1	146.5	144.0	143.3	146.2
2	144.1	145.4	146.0	144.4
3	142.6	146.8	145.0	143.2
4	145.9	142.9	144.7	145.3
Delta	4.0	3.9	2.7	3.0
Rank	1	2	4	3

Analysis of variance

ANOVA is a well-grounded tool for the evaluation of experimental wear tests [37]. The result of the application ANOVA for the wear performance of our WNP/BF/EP composite is shown in Table 6. The sliding velocity and fiber content were the more influencing parameters on the composite wear, where the sliding distance and normal load had a lesser effect. The P-value of the sliding velocity was 0.319 for the BF/WNP /EP composite, which indicates that there was a negative effect of sliding velocity on the specific wear rate for the f composite reinforced fiber.

Table 6. ANOVA for S/N ratio BF/WNP.

Analysis of Variance for S/N ratio Banana fiber/WNP/EP composites, using the Adj SS for the Tests							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**P.C %**
Sliding velocity (m/s)	3	38.941	38.941	12.980	1.81	0.319	29.86
Walnut content (wt.%)	3	35.508	35.508	11.836	1.65	0.346	27.22
Normal load (Newton)	3	14.807	14.807	4.936	0.69	0.617	11.35
Sliding distance (m)	3	19.602	19.602	6.534	0.91	0.530	15.03
Error	3	15	21.544	7.181			16.52
Total	15	130.402					
DF - Degree of freedom, Seq SS - Sequential sum of squares, Adj SS - Adjacent sum of squares, Adj MS - Adjacent sum of mean squares, F – Variance, P - Test statistics, P.C- Percentage Contribution							

Scanning Electron Microscopy (SEM) analysis

Micrographs of Scanning electrons were taken to analyze the post sliding wear effect on the samples, as in Figure 8 (a - f). Along the plane of crack propagation, the micrograph of a fractured surface exhibits signs of fibre fracture, fibre pullout, matrix cracking, and fiber-matrix debonding, Figure 8 (a-b). The presence of more ends and alignment in the fiber generally bears the applied load and transfers it to the other end of the composite via matrix, thus improving the composite's wear properties [38]. Sliding wear causes abrasion, adhesion, and surface fatigue. Moreover, debris (Not in all) formation and flattening of surfaces may also be caused during sliding wear operation, Figure 8 (c). The sliding wear rate is more dependent on hardness than sliding velocity, normal load, sliding distance, and walnut content since higher hardness leads to a lesser wear rate. Moreover, the WNP is less dense thus it accumulated at both surfaces of the composite, which leads to more interaction of WNP with the sliding surfaces than of the BF or EP. For this reason, the WNP played an essential role in reducing the wear of the banana fiber reinforced polymer composite, as evident from Figure 8 (c and d). SEM observation also revealed that the formation of wear debris and potholes during sliding wear existed at the samples' surfaces containing WNP, at higher load and velocity. Abrasive wear accompanied with surface fatigue was also observed at the specimens surface, but abrasive wear remained more dominant, as shown in Figure. 8 (e and f). Figure 8 (d) shows higher void formation, which was at 15 wt. % WNP loading, followed by 10 wt. % WNP as in Figure 8 (e). An increase in the void fraction also affects the composite's overall properties, as shown in Figure. 8 (e, f). Moreover, WNP has a higher tenacity than BF, due to which the composite surface becomes harder with

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increasing WNP loading. The hard surfaces formed by the inclusion of walnut powder lead to a comparatively low wear rate, which correlates with past research [39,40].

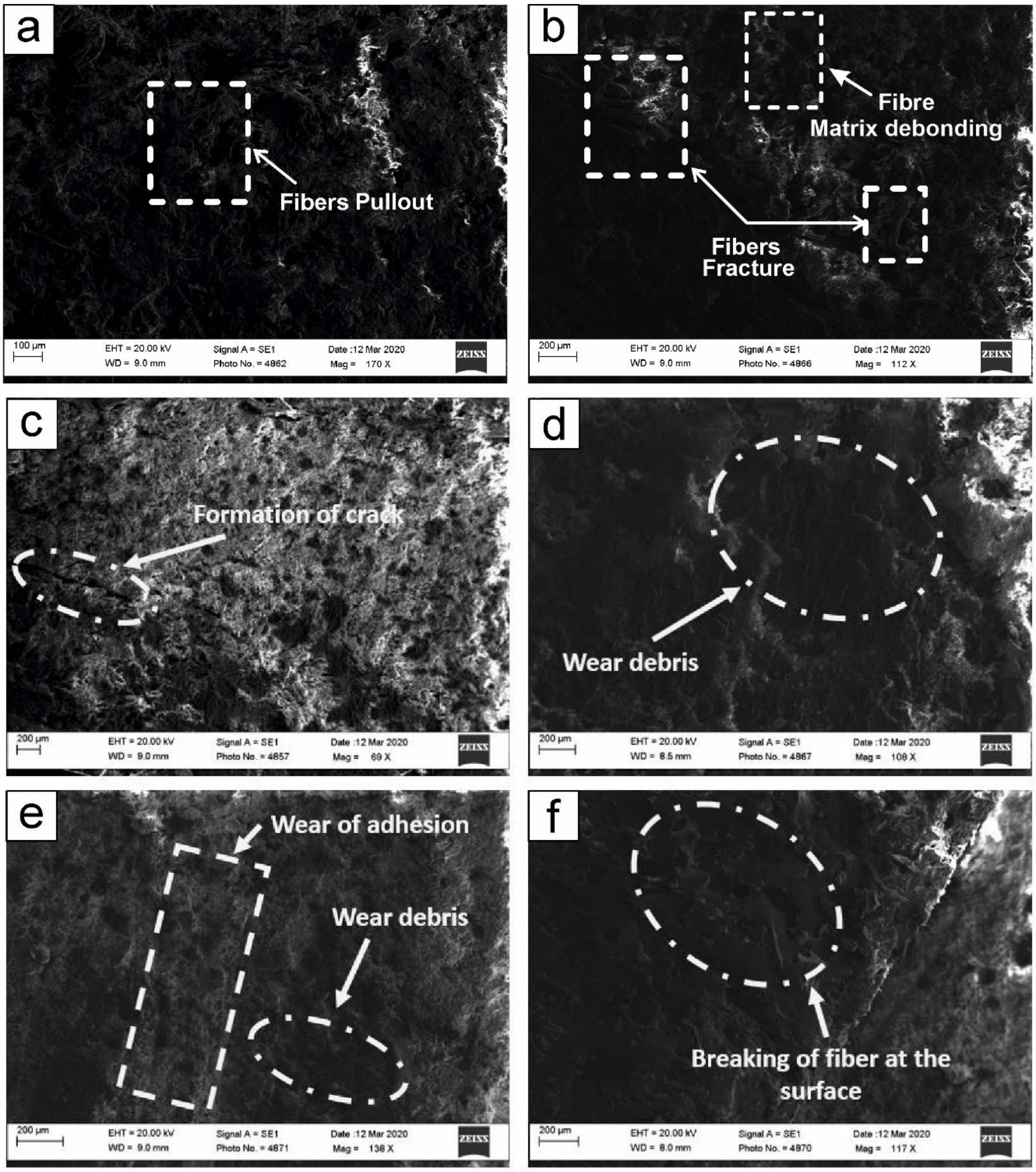

Figure 8. Worn surface morphology of the fabricated composites.

From the above discussion, it is accomplished that better wear resistance is offered at greater sliding velocity (3.5 ms-1) and filler content of 15 wt.%, but a normal load of 20N, and sliding distance of 1800m hybrid composites.

Application and Future scope

It has also been claimed that hybridization of banana/WN/epoxy composites not only enhanced the mechanical properties of the composite, but it also lowered the wear rate of the composite. As a result, the composites that are generated will be extremely suited for vehicle parts as well as for all forms of lightweight engineering applications in general.

Impact

The current investigation is focused on the study of physio-mechanical properties of banana fiber (BF), fiber-based epoxy (EP) composites filled with walnut shell powder (WNP). The experimental results revealed a positive result of using the selected material in the composite. The addition of walnut powder in the BF/EP composites enhances the wear resistance. The major impact of the present investigation is the environmental benefit as the sustainable materials containing mainly natural entities for composite fabrication reduces the greenhouse effect and are biodegradable. This will encourage the use of natural fibers in composite materials, bringing down the high cost of manufacturing synthetic fiber-based polymer composites.

Conclusions

Green composites made from non-woven banana fiber/WNP/EP composites were successfully manufactured utilizing the hand lay-up method. Analysis of green composites can lead to the following conclusion.

- The inclusion of Walnut powder contents led to a decrease in density, increases in void although led to enhance tensile, hardness, impact, and flexural strength.
- According to the Taguchi method's response table, the control factors that influenced wear performance were sliding velocity> fibre content > sliding distance > Normal load. The combination that provided the lowest wear rate was 5wt% walnut powder (BW2) at 1.5 m/s sliding velocities, under load of 20 N at a distance of 1300 m.
- The worn surface micrographs of banana / WN / epoxy composites have shown the related wear mechanisms which were liable for the wear as experimentally found.

Conflicts of interest

There are no conflicts to declare.

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