Ascertaining Tribological Properties of PLA Matrix Composites Reinforced with SCB/CF Fiber with ANOVA and Regression Analysis

Nitin Mukesh Mathur
Department of Mechanical Engineering, Poornima University

Yashpal
Department of Mechanical Engineering, Poornima University

Pratap, Bhanu
Department of Mechanical Engineering, Poornima Institute of Engineering and Technology

https://doi.org/10.5109/7172260

出版情報：Evergreen. 11 (1), pp.234-241, 2024-03. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Ascertaining Tribological Properties of PLA Matrix Composites Reinforced with SCB/CF Fiber with ANOVA and Regression Analysis

Nitin Mukesh Mathur[1], Yashpal[2], Bhanu Pratap[3,*]

[1] Department of Mechanical Engineering, Poornima University, Jaipur, India (302022)

[2] Department of Mechanical Engineering, Poornima University, Jaipur, India (302022)

[3] Department of Mechanical Engineering, Poornima Institute of Engineering and Technology, Jaipur, India (302022)

*Author to whom correspondence should be addressed:
E-mail: bhanu.pratap@poornima.org, bhanu132@yahoo.com

(Received December 29, 2023; Revised March 05, 2024; Accepted March 16, 2024)

Abstract: Lots of availability of plant fibres as well as animal fibres as a filler materials and easy manufacturing techniques researchers have been enticed to investigate whether locally accessible, low-cost fillers can be used for reinforcement and whether they meet the necessary requirements for a reinforced polymer composite for tribological applications. In this work a new hybrid composite were developed with Sugarcane bagasse and chicken feather fibres with PLA as matrix material. Sugarcane bagasse is a plant fibre rich in cellulose while chicken feather is animal fibre rich in keratin, mixed with Polylactic acid biodegradable matrix material. Samples were made by Compression moulding machine followed by melt mixing. The samples were prepared according to ASTM standards and tested on "Pin on disc wear tester" to identify its wear properties. For optimum results we applied Taguchi technic of L18 orthogonal array. The combination of natural fibres and biodegradable matrix material play a very important role and makes it ecofriendly with various applications.

Keywords: Composite Material, Polymer, PLA, Tribology, Wear rate, Regression, ANOVA, Taguchi.

1. Introduction

The researchers have diligently done the research work on various combination of various natural plant fibres, animal fibres and synthetic fibres etc [1-3]. Being the topmost producer of sugarcane, the maximum sugarcane is used in sugar mill, juice or for eating. Bagasse is the byproduct which is generated after the extraction of juice. The most of the bagasse is used for feeding the animals and burned for food preparation [4-6]. This raw bagasse is utilized as a natural material for filling with various matrix materials such as Tripathi [7] et al studied epoxy based composite with Sugarcane bagasse, Tarini [8] et al mixed bagasse with PLA and identify mechanical and morphological properties of the samples.

Currently, a large quantity of chicken feather is growing day by day due to increase number of non-vegetarian people, which results decomposition problem of large animal waste [9-12]. Traditional method of decomposition is creating environmental problems so proper utilization is demand of today [13-15]. Chicken feather is animal waste which cannot decompose directly to the land, proper valorization is needed for landfill. Most of the chicken feather is wasted but it contains large amount of Keratin which is a kind of protein [16-18]. Tarkan [19] et al researched regarding the thermal characteristics of the feather of chicken fibre taking PLA based composite, Avi raj [20] et al studied about epoxy based composite with Chicken feather fibre.

Polylactic acid is also largely used as matrix materials because of its attractive mechanical properties, biodegradable nature and relatively low in cost. It is largely used for 3D printing, Composite materials, biomedical engineering, automotive industry, packaging materials, plastic industry and agriculture etc [21-23]. In this study, the researchers have prepared the combination of natural plant fibre Sugarcane bagasse and the cattle fibre chicken feather consisting of Polylactic acid as a matrix material by compression moulding process, which makes it environment friendly in nature [24-26].

The wear property including polymer composite materials enhance its application in various fields. Many researchers studied about tribological properties of composite materials such as Haseebuddin [27] et al fabricated sugarcane bagasse fibre with vinyl ester as matrix material. It was found that least wear rate at twenty percent of sugarcane fibre. Bagasse shows excellent wear resistant with increases fibre percentage.

Rajni [28] et al studied the combination of Cyperus pangorei Fiber Reinforced Polyester Composites by using compression molding process. By performing pin on disc test at various speeds, it was identified that wear rate increases with increases applied load due to presence of fibre breaking and pulverization. Francis O [29] et al identify the tribological characteristics of Polyester based Composite Reinforced with wood charcoal and Periwinkle Shell , optimum value of wear was found at 5 percentage weight of wood charcoal, as the periwinkle shells added then value of wear slightly decreases. Aigbodion [30] et al studied about wear properties of raw sugarcane bagasse with recycled low density polyethylene as a matrix material, it was analyzed that wear resistance increases with increases percentage of sugarcane bagasse ash. ANOVA analysis reveals that applied load and sliding speed have the highest influence on wear property. Mahapatra [31] et al developed a multi-phase hybrid composite material with polyester reinforced with e-glass fibre and ceramic as filler materials. Which are further filled with cement by-pass dust (CBPD), alumina (Al_2O_3) and silicon carbide (SiC) at different percentage. It was examined that cement by pass product increases wear resistance as compared to other filler materials. R. Sharma et al. [19] conducted a study to investigate the impact of Al_2O_3/SiC on the tensile and flexural properties of epoxy-based glass fiber-reinforced hybrid polymer composites. R. Sharma et al. [32] evaluation revealed that GFRP with Al_2O_3/SiC (1:1) fillers exhibited a decrease in chemical resistance as the quantity of particulates increased over time during immersion in chemical substances. K. Karthik et al [33] studied about epoxy based composite with carbon, kewlar and e-glass fibres by hand layup technic, they used taguchi method with L_9 orthogonal array. It was found that combination of carbon and kewlar gives better wear property which can be used in automobile industry. A. Agrawal et al. [34] studied solid glass microsphere in micro size with epoxy based composite made by hand layup technique. Results reveals that as the filler percentage increases mechanical properties also increases and wear rate decreases. A. Agrawal et al. [35] studied a hybrid combination of short sisal fibre with hexagonal boron nitride with epoxy as matrix material. Hand layup technic were used to make samples and it was identified that water absorption, density increases with percentage. Tensile properties also increases by adding sisal in HBN, due to which it got more ductile.

Researchers have worked on a variety of hybrid combinations, but we use a compression molding machine to create hybrid combinations of natural plant cellulose based fibre and animal keratin based fiber with a biodegradable matrix material that are environmentally benign. [36-38] Researchers also reveals that properties such as physical, chemical, mechanical and wear etc, depends on various parameters such as particle size, mixing temperature etc also play a crucial role for proper applications. [39-41].

Material and methodology

1.1. Materials

The matrix material, PLA (Poly Lactic Acid- E3051D was obtained from Vruksha composites in Hyderabad, India. The specific gravity of 1.26 g/10 min and the flow index of melt is 25.12 g/10 min (2.17 kg load, 212^{0}C). A density of the material is 0.32-0.33 gm/cm3. The sugarcane bagasse was obtained from a local juice vendor in Mansarover, Jaipur. The keratin-based fiber, chicken feathers were bought from the Mahaveer poultry farm situated at Nevta, Jaipur.

1.2. Preparation of fiber

Both the filler fibers were dried under the sun for a period of 48 hours. Afterwards, they were washed using hot water to eliminate any impurities and dust particles. The SCB fibers were then crushed using a grinder machine and subsequently gathered using a sieve shaking machine. Additionally, they were treated with a 10% NaOH solution to enhance their binding capabilities due to high density of the fibres.

1.3. Fabrication of composites

A hybrid composite material was created using sugarcane bagasse (SCB) and cellulose fiber filler (CFF) as reinforcement materials, with an average SCB length of 2-3 mm and diameter of 15-25µm, and approx. CFF length of 2-3 mm and diameter of 05-20µm. A melt-mixing approach was employed for the fabrication of PLA/SCB and PLA/SCB/CF composites. The PLA pellets used in the experiment were demoisturized in a vacuum oven at 55°C for 3 hours to remove any moisture present which might trap the air bubble during composite fabrication. Thereafter, 20 g of PLA pellets was feed to an internal mixture (SMX-101, Sigma mixture) at 190°C with rotational speed of 60 rpm. As the pellets starts melting and in semisolid form, (3, 6, and 9) wt% of SCB and 5 wt% of CF were slowly fed into the mixture to make different composites. After 5 minutes of mixing, the semisolid composite was taken out from machine (internal mixture) and then compression molded (4DL10SGD-10, Universal Hydraulic Press with Hot Plate, Polyhydron PVT. LTD, India) into approximately 3 mm thick sheets with hot press at 180°C by applying a slowly increasing force from 0 to 25 MPa for about 10 minutes Three samples were prepared for the calculation of each property of the composite. Samples were taken for various tests following ASTM Standards.

Table 1. The weight percentage composition of Sugarcane bagasse, chicken feather and Polylactic acid.

Sample	Composition		
	SCB	CF	PLA
	3	0	97
	6	0	94
	9	0	91
	3	5	92
	6	5	89
	9	5	86

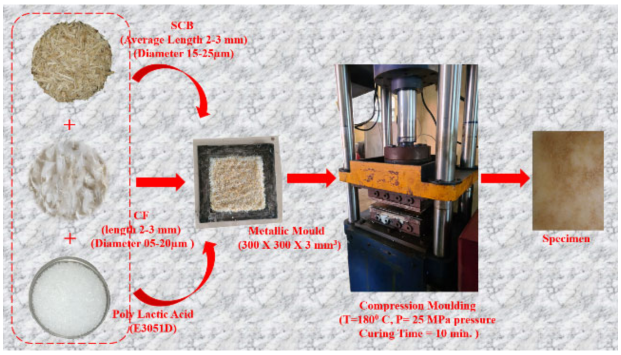

Fig. 1: The process of Fabrication specimen with the use of compression moulding.

2. Experimental details

2.1 Pin on Disc Setup for wear test

The wear test set- up of a PLA hybrid composite containing SBC/CF fillers were assessed through a pin-on-disc test on Model: TR-201LE-M8, Rotating disc: EN31 steel hardened to 60 HRC, Ducom Instruments PVT. Ltd., Bengaluru-560058, Karnataka, India, via Rectangular samples with dimensions of 10 x 10 mm in cross-section and a length of 30 mm was prepared, followed by polishing and machining as per ASTM G99. To ensure a flat contact surface between the PLA hybrid composite sample. It is the pin along with a disc in rotation, the pin took balance with a counterweight, which served as the applied load during the entire experimental procedure.

Based on the findings from the reviews of related literature, the selected dimensions included the reinforcement of weight percentage, normal load (N), sliding velocity (m/s), and sliding distance (m). The sliding distance varied in the experimental range of 300-900, while other parameters such as load (10, 15, 20 N), sliding velocity (1, 2, 3 m/s) and reinforcement percentage (3, 6, 9, 3+5, 6+5, 9+5 wt.%) were also altered. The load cell of LVDT attached to a lever arm was employed to monitor wear with respect to given time by tracking the arm's motion. As the experiment progressed and the pin's surface wore out due to friction, the lever arm descended under the applied load to maintain contact between the pin and the disc. The motion of the lever arm generated a signal, which was utilized to measure wear, meanwhile the coefficient of friction also recorded. Weight loss also calculated by weighing each sample before and after the test by using a weighing machine of a single pan.

Factors that contribute to the increase in wear resistance observed in pin-on-disc experiments of SCB/CF reinforced PLA composites may include: Fiber morphology (including their length, diameter, and aspect ratio), fiber content (Higher fiber content typically results in increased wear resistance), fiber orientation (Proper alignment and orientation of fibers within the matrix can improve wear resistance), interfacial bonding, surface modification (treated with a 10% NaOH solution), environmental conditions, matrix properties.

Fig. 2: Pin on disc tribometer.

2.2 Taguchi Method

Taguchi method is the statistical tool for robust Design. Experiments were performed by L18 orthogonal array. Taguchi reduces the number of responses as compared to conventional experimental method with effective, quick and systematic approach. Taguchi analysis is a powerful tool in optimizing the manufacturing process of polymer composites, leading to improved performance, cost-effectiveness, and reliability.

In this study, we considered four parameters, namely, the filler percentage (A), normal load (B), sliding velocity (C), and sliding distance (D), each at three different levels. While a complete factorial experiment would require testing all possible combinations of these four parameters at their respective levels, the application of Taguchi's method reduces the number of runs to 18, from what would otherwise be a much larger set, provide better efficiency.

Table 2. Different Parameters for wear test.

Control Parameters	Symbols	Fixed Parameters	
Percentage of Filler	Parameter (A)	Test temperature	Room Temperature
Normal Load	Parameter (B)	Time	100 Min.
Sliding Velocity	Parameter (C)	Pin Size	20X20 mm
Sliding Distance	Parameter (D)	Disk Size	120 mm

Table 3. Input process parameters with levels.

Parameters	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Units
Percentage of Filler	3	6	9	3+5	6+5	9+5	Wt%
Normal Load	10	15	20				N
Sliding Velocity	1	2	3				m/s
Sliding Distance	300	600	900				M

From experimental analysis we can find out Signal-to-noise (S/N) ratios. It depends upon type of properties for that various S/N ratios are possible, such as:

$$\text{'smaller} - \text{the} - \text{better'characteristic:}$$

$$\frac{S}{N} = -10 \log \frac{1}{n} (\sum y^2) \quad (1)$$

Where

N Number of observations
Y Observed data
Y Mean
S Variance

The smaller is better' feature applies for minimal erosion rate by using formulae as a logarithmic modification of the loss purpose.

2.3 ANOVA Analysis

ANOVA is a statistical method to analyze the variances among group means in a sample. It divides the total variability observed in a set of data into different components, allowing you to test the hypothesis that the means of multiple groups are equal. ANOVA is commonly used in various fields, including experimental sciences, social sciences, and business, to compare means across multiple groups and identify significant differences. It's essential to ensure that the assumptions of ANOVA are met for valid results.

3. Results and Discussions

3.1. Taguchi analysis

We took four control parameters such as percentage of filler (A), Normal load (B), sliding velocity (C), sliding distance (D) to calculate sliding wear property. The working range of each input parameter has four level as represented in table 2 associated with L18 orthogonal array. Taguchi approach include 18 runs, four parameters at four different levels in Taguchi experimental design. For the analyses and design of experiment, we used MINITAB 16 application software.

In the table 4 the column 2,3,4,5 and 6 represent respectively percentage of filler (A), Normal load (B), sliding velocity(C), sliding distance (D) and wear rate. The table 4 also contains S/N ratio and mean in column 7 and 8 respectively. Each row in the table represents the experimental condition i.e. Combination of various parameters and levels under which specimens were subjected to sliding wear experiment.

The figure 3 exemplifies the main effect of control parameters on sliding wear at four different levels. Also the figure 3 evidently represents how parameter A (3, 6, 9, 3+5, 6+5, 9+5 wt.%), parameter B (10, 15 and 20 N), parameter C (1 to 3 m/s) and parameter D (300 to 900m) change. The most appropriate value of sliding wear is caused at highest S/N value in graph. From the fig.3, it is observed that combination of filler percentage (9+5 wt. %), Normal load (15 N), sliding velocity (1 m/s) and sliding distance (900m) give minimal specific wear rate.

Table 4. Experimental design using L18 orthogonal array for different percentage of weight of SBC/CW PLA based composites for wear along with S/N ratio and mean.

Runs	Filler Percentage	Normal Load	Sliding Velocity	Sliding Distance	Wear Rate	SNRA1	MEAN 1
1	3	10	1	300	0.00042	67.535	0.00042
2	3	15	2	600	0.00047	66.558	0.00047
3	3	20	3	900	0.00045	66.9357	0.00045
4	6	10	1	600	0.00051	65.8486	0.00051
5	6	15	2	900	0.00035	69.1186	0.00035
6	6	20	3	300	0.00038	68.4043	0.00038
7	9	10	2	300	0.00039	68.1787	0.00039
8	9	15	3	600	0.00041	67.7443	0.00041
9	9	20	1	900	0.00028	71.0568	0.00028
10	3+5	10	3	900	0.00032	69.897	0.00032
11	3+5	15	1	300	0.00029	70.752	0.00029
12	3+5	20	2	600	0.00032	69.897	0.00032
13	6+5	10	2	900	0.00027	71.3727	0.00027
14	6+5	15	3	300	0.00029	70.752	0.00029
15	6+5	20	1	600	0.00031	70.1728	0.00031
16	9+5	10	3	600	0.00034	69.3704	0.00034
17	9+5	15	1	900	0.00022	73.1515	0.00022
18	9+5	20	2	300	0.00029	70.752	0.00029

Table 5. Response Table for S/N ratio (Smaller is better)

Level	Filler Percentage	Normal Load	Normal Load	Sliding Distance
1	67.01	68.7	69.75	69.4
2	67.79	69.68	69.31	68.27
3	68.99	69.54	68.85	70.26
4	70.18	-	-	-
5	70.77	-	-	-
6	71.09	-	-	-
Delta	4.08	0.98	0.9	1.99

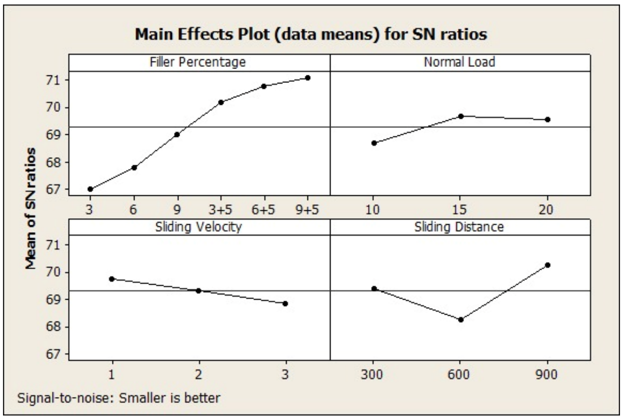

Fig. 3: Main effects plot for S/N ratio on different percentage of SBC and CW PLA based composites in wear.

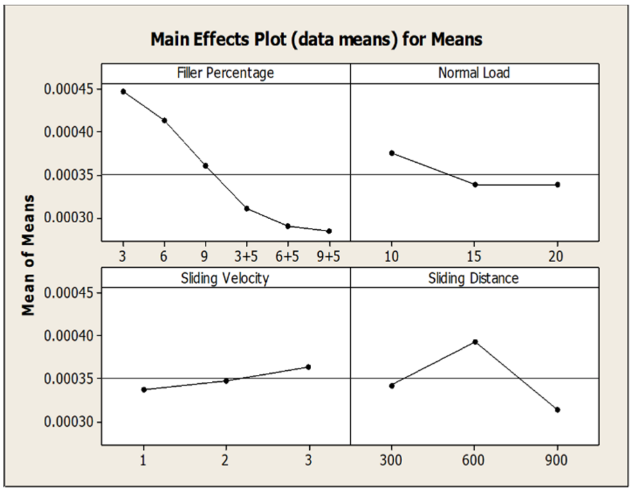

Fig. 4: Main effects plot for mean on different percentage of SBC and CW PLA based composites in wear.

3.2. Analysis of variance and the effects of factors

In order to identify the design parameters that have a significant effect on the quality characteristic Analysis of variance (ANOVA) is used. The analysis of variance was calculated by considering four parameters, including changes in filler percentage (A), normal load (B), sliding velocity (C), and sliding distance (D), by using MINITAB 16. The outcomes of the analysis of variance for signal-to-noise (S/N) ratios are presented in table 7. A confidence level of 95% was applied in the analysis. For every design parameter, the F- value was computed. The F- value greater than four (F > 4) suggests that the factor is highly significant and has a more noticeable impact on the ideal attribute. The results presented in Table 7 show that changes in filler percentage (A), normal load (B), sliding velocity (C), and sliding distance (D) had lower significance. The penultimate column in Table 6 reflects the p-value's significance. P-value less than 0.05 (P < 0.05), denotes a high level of significance and a more pronounced effect of the component on the ideal characteristic. The analysis in Table 7 demonstrates that changes in filler percentage (A), normal load (B), sliding velocity (C), and sliding distance (D) held greater significance. Improved wear resistance is attained through longer SCB (2-3 mm and diameter of 15-25µm) or CF (2-3 mm and diameter of 05-20µm) fiber lengths and higher fiber content (9 wt% SCB + 5 wt% CF), as they enhance the interfacial adhesion between the fibers and the matrix. The quality of the bond between SCB or CF and the PLA matrix is crucial for wear resistance. Strong interfacial bonding prevents fiber pull-out and enhances load transfer, consequently increasing wear resistance. Surface treatments thought 10% NaOH solution applied to SCB or CF fiber were enhance wear resistance by reducing friction and increasing interfacial Bonding.

Table 6. Control parameters impact on wear rate.

Factor	Type	Levels	Values
Percentage of Filler (A)	Fixed	6	3, 6, 9, 3+5, 6+5, 9+5
Normal Load (B)	Fixed	3	10, 15, 20
Sliding Velocity (C)	Fixed	3	1.0, 2.0, 3.0
Sliding Distance (D)	Fixed	3	300, 600, 900

Table 7. Analysis of variance for S/N ratios.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution (%)
Filler Percentage	5	41.2616	41.2616	8.2523	13.55	0.003	65.84
Normal Load	2	3.3558	3.3558	1.6779	2.76	0.142	5.35
Sliding Velocity	2	2.4422	2.4422	1.2211	2.01	0.215	3.90
Sliding Distance	2	11.9563	11.9563	5.9782	9.82	0.013	19.08
Error	6	3.6533	3.6533	0.6089			
Total	17	62.6692		Total			

Table 7's last column shows the percentage that each parameter contributed to the overall variation, demonstrating how much of an impact it had on the result. The wear rate of PLA-based composites was significantly influenced by sliding distance (19.08%) and filler content (65.84%), as shown in Table 7. Conversely, there was no discernible impact of sliding velocity (3.90%) or normal load (5.35%) on the wear rate.

3.3. Regression analysis and genetic algorithm

The experimental data was subjected to linear regression analysis in order to determine a correlation between the test parameters and the composite materials' rate of wear. Under various test parameter configurations, the wear rate of composites can be predicted by this regression model. The resulting regression equation was then used to develop a fitness function for genetic algorithm optimization. The fitness function and the regression model are represented, respectively, by equations (2) and (3).

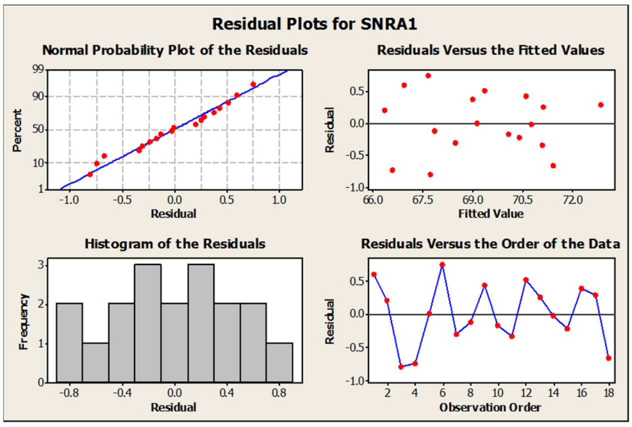

Fig. 5: Residual Plots for Wear.

The regression equation is Wear

= 0.000544 - 0.000016 Percent of Filler - 0.000004 Normal Load + 0.000013 Sliding Velocity - 0.000000 Sliding Distance

= 0.000544 - 0.000016 (A) - 0.000004 (B) + 0.000013 (C) - 0.000000 (D) …………. (2)

Wear= @ (x) + 0.000544 - 0.000016 (x1) - 0.000004 (x2) + 0.000013 (x3) - 0.000000 (x4) …………. (3)

A non-conventional approach, the Genetic Algorithm, was employed for optimizing the wear test parameters. The optimization process was carried out using the MATLAB 2014 software package. The fitness function, derived from equation (2), was used as the basis for optimization. In equation (3), the variables x1, x2, x3, and x4 represent the percent of filler, normal load, sliding velocity, and sliding distance, respectively, serving as input chromosomes for the genetic algorithm. The mean fitness function and optimal fitness function during the optimization process are shown in Fig. 5. Furthermore, the software-generated regression coefficient (R^2 = 94.17%) suggests that the experimental data is well-represented and satisfactory.

4. Conclusions

The novelty of the article lies in the exploration of locally available, low-cost filler materials for reinforcement in biodegradable PLA matrix materials for tribological applications. Specifically, the study introduces a new hybrid composite comprising Sugarcane bagasse and chicken feather fibers incorporated into a Polylactic acid (PLA) matrix. Sugarcane bagasse, rich in cellulose, and chicken feather, rich in keratin, offer unique properties when combined with the biodegradable PLA matrix material. The use of these natural fibers and biodegradable matrix material not only enhances the wear properties of the composite but also makes it eco-friendly. The article also employs the Taguchi technique of L18 orthogonal array for optimizing the composite's wear properties, demonstrating a systematic approach to material optimization. Overall, the research contributes to the development of sustainable and cost-effective, and biodegradable matrix material presents an eco-friendly solution with potential applications across various industries. We made following conclusions based on the research work did here:

1. Successfully fabricated hybrid combination of SCB fibre and CF fibre with PLA matrix by Compression molding process.
2. Wear characteristic can be successfully analyzed using Taguchi method as it provides a systematic, simple and efficient method by optimizing of control factors.
3. Optimum value of minimum wear rate found at filler percentage (9+5 wt. %), Normal load (15 N), sliding distance (900 m) and sliding velocity (1 m/s).
4. Improved wear resistance is attained through longer SCB or CF fiber lengths and higher fiber content (9 wt% SCB + 5 wt% CF), as they enhance the interfacial adhesion between the fibers and the matrix. The quality of the bond between SCB or CF and the PLA matrix is crucial for wear resistance. Strong interfacial bonding prevents fiber pull-out and enhances load transfer, consequently increasing wear resistance.
5. Minimum weight loss (0.00022) found at filler percentage (9+5 wt. %), Normal load (15 N), sliding distance (900 m) and sliding velocity (1 m/s). Uniform orientation and alignment of SCB or CF within the PLA matrix resulted in increased wear resistance by enhancing reinforcement and preventing crack propagation.
6. ANOVA analysis shows that filler percentage (65.84%) and sliding distance (19.08%) shows significant impact on the wear property. In contrast, normal load (5.35%) and sliding velocity (3.90%) showed no significant effect on the wear rate.
7. A strong correlation of (R2=94.17%) between the experimental data and the mathematical model implies that the specific wear values predicted by the model closely align with the actual values obtained in the experiments.

In future, this study can be further extended by changing composition of the filler or matrix materials.

References

1) A. Kumar, A.K. Chanda and S. Angra, "Optimization of stiffness properties of composite sandwich using hybrid taguchi-gra-pca," Evergreen, 8 (2) 310–317 (2021). doi:10.5109/4480708.

2) D. Ariawan, W. P. Raharjo, K. Diharjo, W. W. Raharjo and B. Kusharjanta, “Influence of tropical climate exposure on the mechanical properties of rhdpe composites reinforced by zalacca midrib fibers,” Evergreen, 9 (3) 662–672 (2022). doi:10.5109/4842526.
3) D. Choudhari, and V. Kakhandki, “Characterization and Analysis of Mechanical Properties of Short Carbon Fiber Reinforced Polyamide66 Composites,” Evergreen, 8 (4) 768-776 (2021). doi.org/10.5109/4742120
4) Soni, A., Das, P. K., Kumar, S., Mishra, V., Pagare, A., & Kumar, D. (2023). Tribological characterizations and numerical simulations of thermoplastic composites in pin-on-disc configuration. Materials Today: Proceedings, 79, 92-99.
5) Soni, A., Das, P. K., Kumar, S., & Pagare, A. (2023). Experimental investigations on the tribological behaviour of thermoplastic composites with partial sand replacements. Materials Today: Proceedings, 79, 44-48.
6) Sharma, R., & Sharma, D. (2023). Synthesis and experimental evaluation of tribological behavior of fly ash filled E-glass fiber reinforcement epoxy composites using Taguchi method. Materials Today: Proceedings.
7) Tripathi, P., & Kumar, D. (2016). Study on mechanical behaviour of sugarcane bagasse fiber reinforced polymer matrix composites. SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology, 8(01), 34-42.
8) Nampitch, T., Wiphanurat, C., Kaisone, T., & Hanthanon, P. (2016). Mechanical and morphological properties of poly (lactic acid)/bagasse fiber composite foams. Applied Mechanics and Materials, 851, 31-36.
9) Ali, S. J., Goyal, A., Dadhich, M., & Prajapati, O. S. (2020). Design optimization of prosthesis hip joint using fem and design of experiment approach. Biomedical Engineering: Applications, Basis and Communications, 32(06), 2050048.
10) Zhan, M., & Wool, R. P. (2011). Mechanical properties of chicken feather fibers. Polymer composites, 32(6), 937-944.
11) Z. Xu, L. Yang, Q. Ni, F. Ruan, and H. Wang, "Fabrication of high-performance green hemp/polylactic acid fibre composites," Journal of Engineered Fibers and Fabrics, vol. 14, p. 1558925019834497, 2019.
12) B. O. Baba and U. Özmen, "Preparation and mechanical characterization of chicken feather/PLA composites," Polymer Composites, vol. 38, pp. 837-845, 2017.
13) M. Esmaeili, G. Pircheraghi, R. Bagheri, and V. Altstädt, "Poly (lactic acid)/coplasticized thermoplastic starch blend: effect of plasticizer migration on rheological and mechanical properties," Polymers for Advanced Technologies, vol. 30, pp. 839-851, 2019.
14) R. Khoo and W. Chow, "Mechanical and thermal properties of poly (lactic acid)/sugarcane bagasse fiber green composites," Journal of Thermoplastic Composite Materials, vol. 30, pp. 1091-1102, 2017.
15) M. Li, Y. Pu, V. M. Thomas, C. G. Yoo, S. Ozcan, Y. Deng, et al., "Recent advancements of plant-based natural fiber–reinforced composites and their applications," Composites Part B: Engineering, p. 108254, 2020.
16) R. B. Yusoff, H. Takagi, and A. N. Nakagaito, "Tensile and flexural properties of polylactic acid-based hybrid green composites reinforced by kenaf, bamboo and coir fibers," Industrial Crops and Products, vol. 94, pp. 562-573, 2016.
17) Sharma, R. K., Das, R. K., & Kumar, S. R. (2023). Microstructure, mechanical and tribological properties of high velocity oxy fuel thermal spray coating: A review. Materialwissenschaft und Werkstofftechnik, 54(1), 90-97.
18) Sharma, R., & Sharma, D. (2023). Synthesis and experimental evaluation of tribological behavior of fly ash filled E-glass fiber reinforcement epoxy composites using Taguchi method. Materials Today: Proceedings.
19) Akderya, T., Özmen, U., & Baba, B. O. (2020). Investigation of long-term ageing effect on the thermal properties of chicken feather fibre/poly (lactic acid) biocomposites. Journal of Polymer Research, 27(6), 162.
20) Manral, A. R. S., Gariya, N., Bansal, G., Singh, H. P., & Negi, P. (2020). Structural and modal analysis of chicken feather fibre (CFF) with epoxy-resin matrix composite material. Materials Today: Proceedings, 26, 2558-2563.
21) Sharma, R., & Sharma, D. (2023). Synthesis and experimental investigation of physical behavior of coconut shell particular and walnut shell particular filled epoxy polymer composites. Materials Today: Proceedings.
22) Gupta, P. K., Sharma, R., & Kumar, G. (2021). Impact of water particles on fly ash–filled E-glass fiber–reinforced epoxy composites. In Advanced Materials and Manufacturing Processes (pp. 257-267). CRC Press.
23) M. K. Gupta, V. Singhal and N. S. Rajput, “Applications and challenges of carbon-fibres reinforced composites: a review,” Evergreen, 9 (3) 682–693 (2022). doi:10.5109/4843099.
24) A. Kumar, A.K. Chanda and S. Angra, “Numerical modelling of a composite sandwich structure having non metallic honeycomb core,” Evergreen, 8 (4) 759–767 (2021). doi:10.5109/4742119.
25) A.C. Opia, M.K.A. Hamid, S. Syahrullail, A.I. Ali, C.N. Johnson, I. Veza, M.I. Izmi, C.D.Z. Hilmi and A.B. Abd Rahim, “Tribological behavior of organic

anti-wear and friction reducing additive of zddp under sliding condition: synergism and antagonism effect," Evergreen, 9 (2) 246–253 (2022). doi:10.5109/4793628.
26) Mathur, N. M., Yashpal, & Pratap, B. (2023). Development and evaluation of physical properties of PLA matrix composites reinforced with SCB/CF fiber. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 09544062231179991.
27) Khaleefa, M. R., & Kumar, P. Study on Wear Behaviour of Bagasse Filler Reinforced Vinyl Ester Composites.
28) Rajini, N., Mayandi, K., Siengchin, S., Ayrilmis, N., Bennet, C., & O. Ismail, S. (2021). Tribological properties of cyperus pangorei fibre reinforced polyester composites (friction and wear behaviour of cyperus pangorei fibre/polyester composites). Journal of Natural Fibers, 18(2), 261-273.
29) Edoziuno, F. O., Akaluzia, R. O., Odoni, B. U., & Edibo, S. (2021). Experimental study on tribological (dry sliding wear) behaviour of polyester matrix hybrid composite reinforced with particulate wood charcoal and periwinkle shell. Journal of King Saud University-Engineering Sciences, 33(5), 318-331.
30) Aigbodion, V. S., Hassan, S. B., & Agunsoye, J. O. (2012). Effect of bagasse ash reinforcement on dry sliding wear behaviour of polymer matrix composites. Materials & Design, 33, 322-327.
31) Mahapatra, S. S., & Patnaik, A. (2009). Study on mechanical and erosion wear behavior of hybrid composites using Taguchi experimental design. Materials & Design, 30(8), 2791-2801.
32) Sharma, R., & Sen, R. (2022). Synthesis and investigation of mechanical behavior of aluminum oxide/silicon carbide filled bi-directional woven E-glass fiber reinforcement epoxy polymer composites. In Recent Advances in 20) Industrial Production: Select Proceedings of ICEM 2020 (pp. 1-12). Springer Singapore.
33) Sharma, R., & Gupta, P. K. (2022). Synthesis and chemical resistance of aluminum oxide and silicon carbide (1: 1) filled Bi-Directional woven E-glass fiber reinforcement epoxy polymer composites. Materials Today: Proceedings, 62, 767-772.
34) Agrawal, A., Chandraker, S., & Sharma, A. (2020). Physical, mechanical and sliding wear behavior of solid glass microsphere filled epoxy composites. Materials Today: Proceedings, 29, 420-426.
35) Agrawal, A., Awasthi, T., Soni, D. K., Sharma, A., & Mishra, V. (2020). Physical and mechanical behaviour of epoxy/hexagonal boron nitride/short sisal fiber hybrid composites. Materials Today: Proceedings, 28, 2166-2170.
36) Dubey, S. C., Mishra, V., & Sharma, A. (2021). A review on polymer composite with waste material as reinforcement. Materials Today: Proceedings, 47, 2846-2851.
37) Girge, A., Goel, V., Gupta, G., Fuloria, D., Pati, P. R., Sharma, A., & Mishra, V. K. (2021). Industrial waste filled polymer composites–A review. Materials Today: Proceedings, 47, 2852-2863.
38) Kharbanda, S., Bhadury, T., Gupta, G., Fuloria, D., Pati, P. R., Mishra, V. K., & Sharma, A. (2021). Polymer composites for thermal applications–A review. Materials Today: Proceedings, 47, 2839-2845.
39) A. Zhumadilova and S. Zhigitova, "Features of Modern Areas of Solid Waste Disposal," Evergreen, 10 (2) 640-648 (2023). doi.org/10.5109/679.
40) Sharma, R. K., Das, R. K., & Kumar, S. R. (2021). Microstructure, mechanical and erosion wear analysis of post heat treated iron alloy based coating with varying chromium. Materialwissenschaft und Werkstofftechnik, 52(11), 1173-1184.
41) H. Sosiati, N. D. M. Yuniar, D. Saputra, and S. Hamdan, "The Influence of Carbon Fiber Content on the Tensile, Flexural, and Thermal Properties of the Sisal/PMMA Composites," Evergreen, 9 (1) 32-40 (2022). doi.org/10.5109/4774214