

# Investigation on Wear Performance of Sisal Fiber Reinforced Epoxy Composites: Experimental and Statistical Study



K. Palani Kumar, A. Shadrach Jeya Sekaran, and K. Ramya

**Abstract** Sisal natural fiber is an alternative used in engineering applications for manufacturing a variety of products. The present study focuses on the wear performance of woven sisal fiber- epoxy composites using a mathematical model. The experiments were conducted on a pin-on-disc wear tester against EN8 steel by adopting the design of experiments (DOE). Wear loss is predicted by the second-order polynomial Response Surface Method (RSM), and its predictability is asserted by considering the analysis of variance (ANOVA). The parameters applied load, sliding speed, and sliding distance are also investigated in detail. Model suitability is analyzed. From the analysis, it is evident that the model is useful to evaluate the wear performance of sisal fiber epoxy composites.

**Keywords** Sisal · Natural fiber · Wear loss · Coefficient of friction · Pin on disc · Design of experiment (DOE) · Response surface method (RSM)

## 1 Introduction

The green environment for the future has been initiated by the researchers with increased interest to go for alternative materials using synthetic fibers. The abundant availability of nature leads to the usage of natural fibers. They have low density with good specific strength, non-hazardous and eco-friendly [1–18]. Building the global environment with the individual attention towards the society and framing the novel

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environmental policies have enforced the search for green composite materials said to be natural fiber composites [2–4]. Agricultural wastes obtained from rice, sugar cane, pineapple, banana, and coconut are being used for producing a huge quantity of biomass. Natural fibers are also used in various industries as an alternative to the raw materials for manufacturing automotive components. The following literature gives an idea of the multiple goods in manufacturing industries [3–20].

Palanikumar et al. [14] have studied the analysis of different woven composites and found that these composites are suitable for automobiles and related applications. The loss of mass on the surface of a solid progressively is said to be wear [12]. Natural fibers are utilized in various applications of wear and friction. Abrasive wear rates were tested for the bagasse fiber- epoxy and found that the fiber orientation also influences the wear rate [16]. Alkali and acid-treated rice straws are considered to remove impurities, waxy substances and it also improves the quality of fiber. From the observation, enhancement of mechanical properties is identified [17]. Tribological properties of PALF short fiber polymer have experimented for different lengths of range from 2 to 14 mm. load escalates the wear at various loads of like 5 N, 10 N, and 15 N [21].

The hand lay-up process in which the fabrication of sisal fiber polymer is done by adopting a particular weight fraction concerning length variation. They have asserted that the variables considered are directly related to responses [19]. An increase in the ratio of glass fiber weight fraction and parallel sliding direction decreases the coefficient of friction and also increases the rate of wear [11]. The wear rate decreases for the increase of fiber weight in percentage [14].

Short palmyra fiber composites are tested for dry sliding, and found that the fiber percentile and sliding speed are the unique elements that affect the wear. Specific wear rate is predicted beyond the experimental domain [20] polyester composite along with particulate reinforcements are considered to analyze the wear by using Pin on disc tribometer for various speeds as well as loads, the wear resistance is higher for fiber-loaded composite [12]. Natural fiber has comparable mechanical properties and also has an improved resistance to wear. The orientation normal to the sliding is found to be the best orientation, it is considered to be the main parameter that affects the wear and friction [16]. The sisal fibers have excellent resistance to wear hence used for the manufacture of fiberboard, its suitability is to be studied further [15]. The study on natural fibers reveals that, enhancement in wear is obtained for 36% hybrid natural fiber when compared to 12 and 24%. This study suggests that this can be used for replacing the bones or orthopedic implant in humans [22]. Sisal/jute—epoxy is fabricated and tested for wear and its frictional properties with different loads, speeds, and distance inferred that the alkali treatment reduces the wear [10]. The features of sisal-vinyl ester composites are modeled and presented by using Box-Behnken Design with better optimization [2].

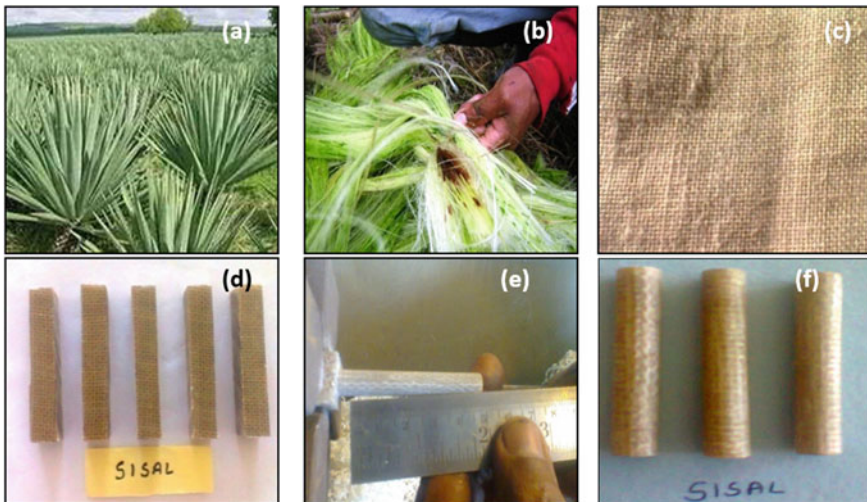
From the analysis, it is found that only very little literature is available, and minimal work is undertaken for referring to the wear properties of woven sisal epoxy composite. No comprehensive experimental design or analysis for woven sisal composites is carried out using Box-Behnken Design. The woven sisal fiber replaces traditional fibers and also has good improvement in the properties of friction and

wear applications. Based on the research gap identified, woven-sisal fiber composite is prepared, its tribological characteristics are analyzed and tested. Modeling and optimization are carried out for wear experiments by statistical analysis with the design of experiments using the Box-Behnken model.

## 2 Materials and Methods

In the present day, natural fibers are considered essential reinforcing agents due to their eco-friendly nature. Also, the cost of manufacturing is found to be low. It has other characteristics like high specific strength, non-abrasiveness, etc. Sisal natural fiber is considered for the present investigation. Figure 1a–c shows the sisal plants, the extraction of sisal fiber, and the woven sisal fiber mat. Epoxy resin is used for the fabrication of composites as a matrix and has better properties than other resin like stiffness, strength, etc. [6]. The hand lay-up process is considered for fabricating the composites. The sisal composite laminates are cut into pre-wear specimens of size  $60 \times 12 \times 12$  mm, which is illustrated in Fig. 1d. The prepared samples are turned into cylindrical pins by using all geared lathe which are represented in Fig. 1e. Pin-wear specimens of the circular shapes are made as per ASTM standard G99 having a length of 50 mm and diameter of 8 mm and are shown in Fig. 1f.

In this investigation, the wear property is analyzed using a tribometer. In this experimental study, the woven sisal fiber composite tribological characteristics are experimented with by various parameters: load, speed, and sliding distance. The



**Fig. 1** a Sisal plants b Extraction of sisal fiber c Woven Sisal fiber d Sisal Specimens e Machining of sisal specimen f Wear Specimens



Fig. 2 Pin on disc tribometer experimental set up

Table 1 Parameters and levels considered for experiments

Parameters	Levels		
	- 1	0	1
Applied load (N)	9.81	19.62	29.43
Sliding speed (m/s)	1.44	2.16	2.88
Sliding distance (m)	1000	2000	3000

disc is prepared for the testing process, having a 55 mm diameter and thickness of 10 mm. A hole is drilled in the middle for fixing purposes. The disc material is EN8 steel. The pin is set in the holder perpendicular to the disc for abrasion. For different speeds, distances and times, the wear rate is observed and recorded. The pin-on-disc machine setup is presented in Fig. 2. The tribological parameters used and their levels identified are given in Table 1.

### 3 Modeling the Tribological Parameters Using Box-Behnken Design

Research is sorted out in the arrangement of exercises to consider, build a model or procedure. It finds the consequences of a sensible issue upheld by writing and testing information. With the end goal that its destinations are streamlined and further make suggestions for implementations. In this investigation, response surface methodology (RSM) is considered for studying the tribological properties using Box-Behnken design. In RSM problems, the connection between the reaction and the free factors is not known. Accordingly, the initial phase in RSM is to locate an appropriate estimation for the genuine utilitarian connection among ‘y’ and set of free factors. On the off chance that the reaction is very much demonstrated by a straight work

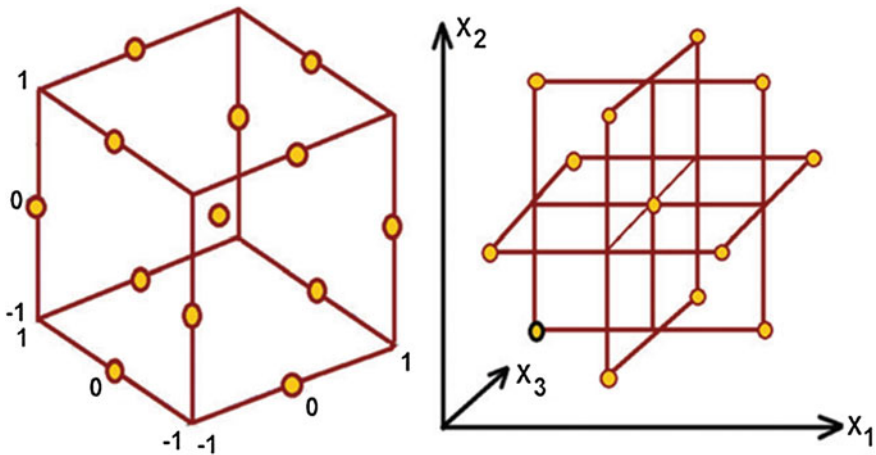
in the autonomous factors, at that point the approximating capacity in the principal request model is composed as:

- (1) If the curvature is considered:
- (2) A second-order quadratic equation is considered for analysis by considering the variables such as applied load ( $W$ ), sliding speed ( $N$ ), and sliding distance ( $S$ ). Experiments are carried out using Box-Behnken design. The selected factors are coded as  $-1, 0, +1$ , and it is arranged in equally spaced values. It has a square term of products of two factors, to arrive in a quadratic model. The ratio of experimental points to the number of coefficients is within the range of 1.5–2.6. Depending on the distance from the center, the estimated variance approximately lies at a higher level inside, the smallest cube containing the experimental points.

Figure 3a, b and Table 2 show Box-Behnken design consisting of three factors. The wear loss is found by using pin- on- disc tribometer by varying the parameters  $W, N$ , and  $S$ . The weight loss for each sample is experimentally obtained by varying loads are 9.81, 19.62, and 29.43 N. The test is carried out as per the Box Behnken design of experiments and the details are illustrated in Table 3.

The quadratic model established for the wear loss of sisal fiber-reinforced composite is presented as follows:

$$\begin{aligned} \text{Wear loss} = & +0.56563 + (7.67074E - 003 * W) \\ & - (0.24097 * N) - (2.74000E - 004 * S) + (3.22092E - 003 * W * N) \\ & + (7.41590E - 006 * W * S) + (5.90278E - 006 * N * S) \\ & - (4.01357E - 004 * W^2) + (0.052807 * N^2) + (6.08750E - 008 * S^2) \end{aligned}$$



**Fig. 3** Box-Behnken design matrix for three factors: **a** A cubical design and **a** Interlocking  $2^2$  factorial design

**Table 2** Three variable Box-Behnken design

Run	$x_1$	$x_2$	$x_3$
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0

where  $W$  is applied load,  $N$  is sliding speed, and  $S$  is the sliding distance.

The results of ANOVA obtained for sisal fiber-reinforced composite material are presented in Table 4, which proves that the applied load is the primary factor, which impacts the wear loss followed by sliding distance. The model adequacy is checked by utilizing the coefficient of correlation. The ratio of correlation observed for wear loss for sisal fiber-reinforced composite is 0.9965, which shows that the models developed are beneficial. F- Model value 218.89 shows that the model is noteworthy. In this case,  $W, N, S, WN, WS, W^2, N^2, S^2$  are capable. The “Lack of Fit F-value” of 3.34 infers which isn’t huge concerning the unadulterated mistake, and hence the model is in fit. The model statistics for the wear loss of sisal fiber reinforced plastic composite are also presented in Table 4. The model statistics indicate that the standard deviation is 0.013, and the coefficient of correlation  $R-Sq$  is 0.9965, which suggests that the model is valid.

The adjacent  $R-Sq$  is observed as 0.9919, and the predicted  $R-Sq$  is 0.9579. The predicted  $R-Sq$  of 0.9579 is in good correlation with the observed  $R-Sq$  of 0.9919. Adequate precision of 52.183 infers that the model has an appropriate signal. This indicates that the model is very useful in predicting wear loss for sisal fiber-reinforced polymer composite. Further, the effectiveness is analyzed by the normal plot of residuals and the correlation graph, which are presented in Fig. 4a, b.

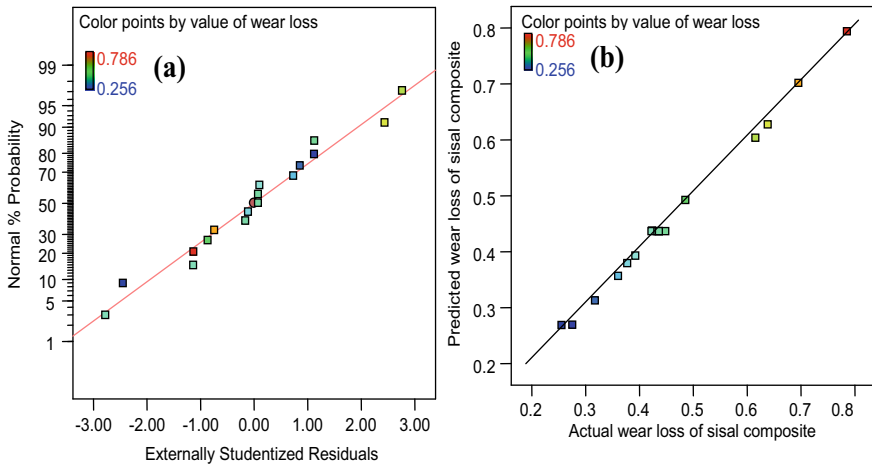
The normal probability of the plot indicates that there is a normality assumption. The points in the model are said to be grouped in a straight line, which suggests that the model is beneficial. Figure 5 indicates the residual analysis of the wear loss model.

**Table 3** Box-Bhenken Experimental design used and results obtained for wear loss and coefficient of friction for Sisal fiber reinforced composite

Std order	Run order	Parameters						Responses		
		Coded values			Real values			Sliding Distance (S) m	Wear loss mm <sup>3</sup> /m	Coefficient of friction
		Applied Load (x <sub>1</sub> ) N	Sliding speed (x <sub>2</sub> ) m/s	Sliding Distance (x <sub>3</sub> ) m	Applied Load (W) N	Sliding speed (N) m/s	Sliding Distance (S) m			
1	3	-1	-1	0	9.81	1.44	2000	0.256	0.449	
2	5	1	-1	0	29.43	1.44	2000	0.486	0.528	
3	6	-1	1	0	9.81	2.88	2000	0.318	0.497	
4	15	1	1	0	29.43	2.88	2000	0.639	0.64	
5	7	-1	0	-1	9.81	2.16	1000	0.276	0.485	
6	4	1	0	-1	29.43	2.16	1000	0.393	0.732	
7	14	-1	0	1	9.81	2.16	3000	0.378	0.528	
8	17	1	0	1	29.43	2.16	3000	0.786	0.513	
9	11	0	-1	-1	19.62	1.44	1000	0.361	0.497	
10	1	0	1	-1	19.62	2.88	1000	0.424	0.733	
11	2	0	-1	1	19.62	1.44	3000	0.616	0.562	
12	12	0	1	1	19.62	2.88	3000	0.696	0.512	
13	9	0	0	0	19.62	2.16	2000	0.449	0.589	
14	10	0	0	0	19.62	2.16	2000	0.437	0.581	
15	13	0	0	0	19.62	2.16	2000	0.423	0.593	
16	16	0	0	0	19.62	2.16	2000	0.434	0.584	
17	8	0	0	0	19.62	2.16	2000	0.437	0.596	

**Table 4** Analysis of variance for wear loss of sisal fiber reinforced composite

Source	Sum of squares	df	Mean square	F value
Model	0.34	9	0.038	218.89
W- Applied Load	0.14	1	0.14	841.06
N-Sliding speed	0.016	1	0.016	93.1
0.13	1	0.13	758.76	< 0.0001
WN	2.07E-03	1	2.07E-03	12.03
WS	0.021	1	0.021	123.03
NS	7.23E-05	1	7.23E-05	0.42
W <sup>2</sup>	6.28E-03	1	6.28E-03	36.51
N <sup>2</sup>	3.16E-03	1	3.16E-03	18.34
S <sup>2</sup>	0.016	1	0.016	90.68
Residual	1.21E-03	7	1.72E-04	
Lack of Fit	8.61E-04	3	2.87E-04	3.34
Pure Error	3.44E-04	4	8.60E-05	Pred



**Fig. 4** Normal probability and Correlation graph on wear loss

Figure 5a provides the residuals and the predicted wear loss. The results indicate both positive and negative residuals, which show that the residuals are spread in both directions. This explains the uniform predictability of the model. Figure 5b indicates the relation between the residuals and run numbers. The variations observed in the residuals are low, which shows the effectiveness of the model.

The coefficient of friction (COF) for sisal fiber-reinforced composite is calculated from a pin on disc tribometer by varying *W*, *N*, and *S*. The wear test is carried out



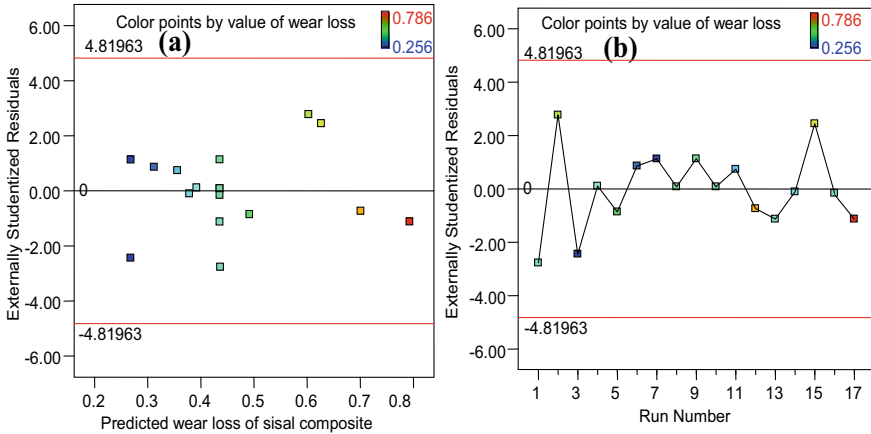


Fig. 5 Residual analysis for wear loss for Sisal fiber reinforced composite

as per the Box Behnken design of experiments in statistics. The parameters and various levels considered are provided in Table 3. The ANOVA prediction obtained for COF is presented in Table 5. From the design values, mathematical relations are established. The quadratic model established is presented as follows:

$$\begin{aligned}
 \text{Coefficient of friction} = & -0.48175 + (0.028843 * W) \\
 & + (0.41674 * N) + (2.57200E - 004 * S) + (2.26526E - 003W * N) \\
 & - (6.67686E - 006 * W * S) - (9.93056E - 005 * N * S) \\
 & - (3.72002E - 004 * W^2) - (0.04687 * N^2) + (1.17000E - 008 * S^2)
 \end{aligned} \tag{2}$$

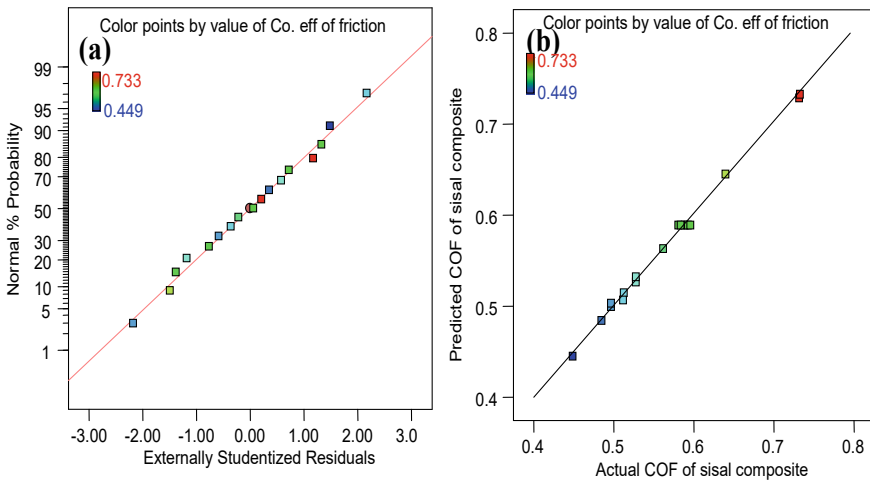
where  $W$  is applied load,  $N$  is sliding speed, and  $S$  is the sliding distance.

ANOVA performed for COF is presented in Table 5. The result proves that the applied load is an effective factor, which influences the wear loss followed by sliding speed.  $R$ -Sq value is used to know the model capability and is 99.71, which shows the model’s effectiveness. The  $F$ -model value 263.56 shows that the model is noteworthy. In this investigation,  $W, N, S, WN, WS, NS, W^2, N^2, S^2$  are effective. The “Lack of Fit  $F$ -value” of 1.28 infers which isn’t huge concerning the unadulterated mistake, and the model is said to be fit. The model statistics for the COF are presented in Table 5. The model statistics indicate that the coefficient of correlation  $R$ -sq is 0.9971, which suggests that the model is adequate.

The adjacent  $R$ -Sq is observed as 0.9933, and the predicted  $R$ -Sq is 0.9746. The difference is less than 0.2. The result indicates that pred-  $R$ -Sq 0.9746 has a good correlation towards the adjacent  $R$ -Sq 0.9933, which suggests the model is beneficial. The adequate precision 57.291 demonstrates that the model helps in predicting the coefficient of friction for sisal fiber-reinforced polymer composite. Further, the effectiveness of the model is analyzed by considering the probability plot of residuals, and the correlation graph, which is presented in Fig. 6a, b. The normal probability

**Table 5** Analysis of variance for coefficient of friction of sisal fiber reinforced composite

Source	Sum of squares	df	Mean square	F Value	p-value	Prob > F
Model	0.1	9	0.011	263.56	<	Significant
W-Applied Load	0.026	1	0.026	600.77	<	
N-Sliding speed	0.015	1	0.015	348.94	<	
S-Sliding Distance	0.014	1	0.014	321.27	<	
WN	1.02E-03	1	1.02E-03	23.88	<0.00	
WS	0.017	1	0.017	400.16	<	
NS	0.02	1	0.02	476.83	<	
W <sup>2</sup>	5.40E-03	1	5.40E-03	125.83	<	
N <sup>2</sup>	2.49E-03	1	2.49E-03	57.97	<0.00	
S <sup>2</sup>	5.76E-04	1	5.76E-04	13.44	<0.00	
Residual	3.00E-04	7	4.29E-05			
Lack of Fit	1.47E-04	3	4.90E-05	1.28	0.39	Not significant
Pure Error	1.53E-04	4	3.83E-05			
Cor Total	0.1	16				
R-squared	0.9971	Adj	R-squared		Pred R-squared	0.9



**Fig. 6** Normal probability and Correlation graph on co efficient of friction

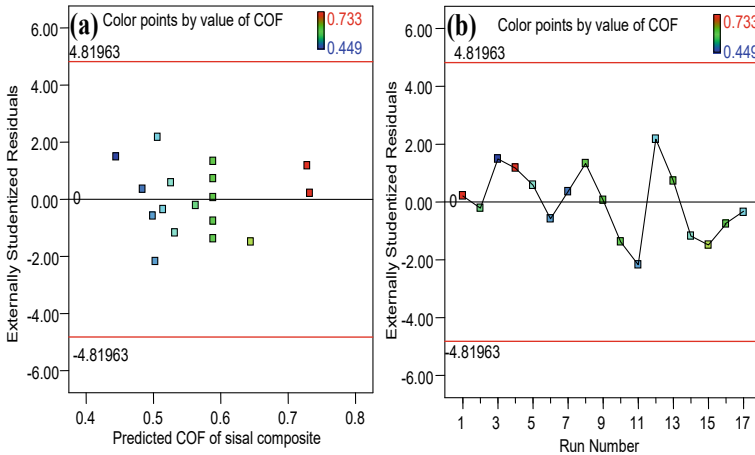


Fig. 7 Residual analysis for co efficient of friction

plot shown proves that there is a normality assumption. The points in the model are said to be grouped in a straight line, which leads to the model being very effective. Figure 7 indicates the residual analysis of the coefficient of the friction model. Fig. 7a provides the residuals and the predicted coefficient of friction. The results indicate both positive and negative residuals, which show that the residuals are spread in both directions. This explains the uniform predictability of the model. Figure 7b provides the relation between the residuals and run numbers and it gives the changes in residuals concerning the run number, and it shows that the model considered is stable. The comparative wear results of sisal fiber composite experiment runs are presented in Fig. 8. The values show the coefficient of correlation between the model developed for tribological testing of sisal composite. The results indicate that the models are fit. The comparison results indicate that the developed model *R-Sq* values are better and closer; hence, this model can be adequately utilized for the forecast of various reactions. The confirmation experiment is carried out for the experiment run of 2, 8, and 12 for wear loss. The comparative test result for the above-said experiment runs along with the experiment, and the predicted and confirmation values are presented in Fig. 9.

The confirmation experiments are carried out for the experiment run of 1, 6, and 14 for sisal fiber-reinforced composite for the coefficient of friction (COF) related to different parameters. From the verification test results, the experimental results and anticipated results are well correlated with each other, and also the error obtained is small. Hence, the model is effective in predicting the tribological characteristics.

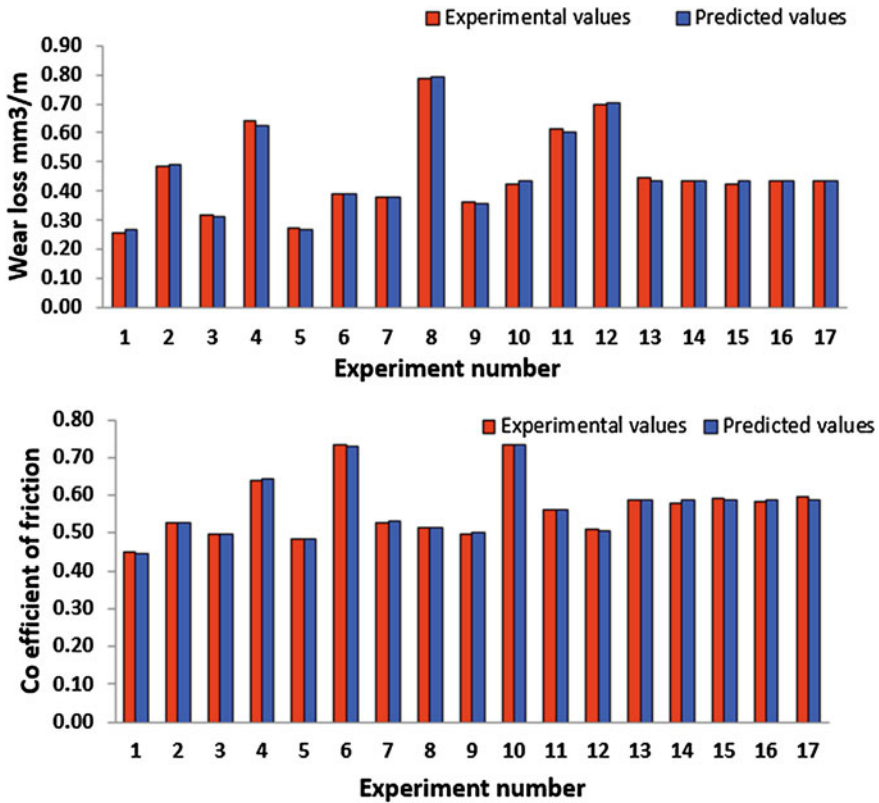


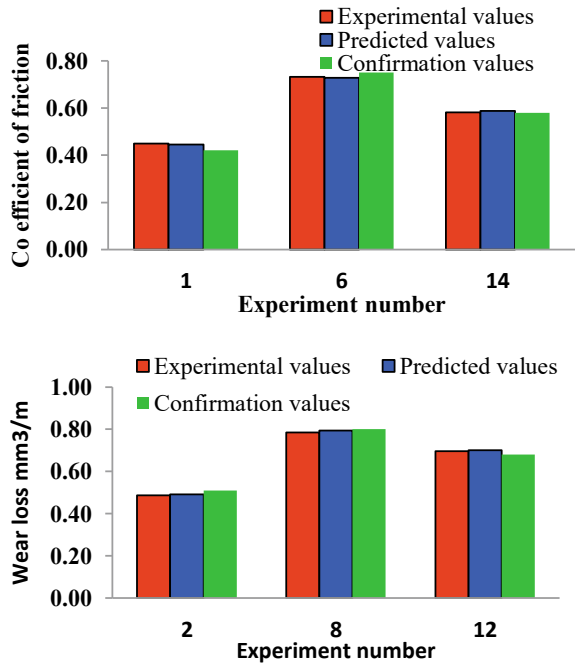
Fig. 8 Comparison chart between the experimental results and RSM predicted results for wear loss and coefficient of friction for Sisal fiber composite

### 4 Results and Discussions

Nowadays, researchers are making progress in replacing synthetic fibers with natural fibers. natural fibers have made their advancements in different areas of Engineering and Technology. Because of its biodegradability, it supports the environment and is also cost-effective. The tribological properties are evaluated for the wear loss and COF for sisal fiber composite by using the Design of Experiment (DOE). Scanning Electron Microscope (SEM) images are considered to dissect the surface.

The wear loss and COF are experimented with and predicted by a pin-on-disc tribometer and by response surface methodology. It is calculated by varying the parameters such as applied loads with different speeds of sliding of 1.44, 2.16, and 2.88 m/s and its variation of sliding distances of 1000, 2000, and 3000 m, respectively. The cylindrical pins prepared from the sisal fiber-reinforced composite samples are made to contact a rotating disc on testing; thus, weight loss for each sample is experimentally obtained by varying the input parameters load, speed, and distance.

**Fig. 9** Verification test result between the experimental, RSM predicted and confirmation experiment results for wear loss and coefficient of friction for Sisal fiber composite

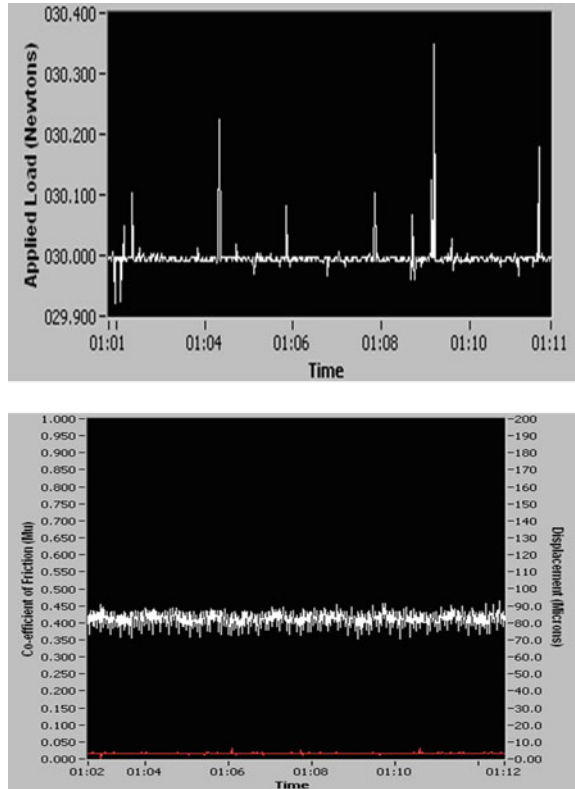


The sample graphs generated from the data acquisition system of the pin-on-disc testing apparatus for sisal fiber-reinforced composite pins, tested under loads of 9.81 to 29.43 N, and the distance of 1000 - 3000 m is represented in Fig. 10. The graph is plotted among the time, applied load, and coefficient of friction. In the graph, it is inferred that there is wear due to the toughness of the fibers.

Sisal fiber-based pins are subjected to similar experimental conditions, which are discussed above, and the parameters concerning wear loss are calculated. When the sliding speed is at 2.16 m/s, the pin is allowed to travel at 2000 m distance for various load conditions, the wear loss is found to increase at a higher rate. The obtained output graph from the model developed is presented in Fig. 11a. When 19.62 N of the load is applied for the same sisal fiber-reinforced composite pin for a 2000 m distance and the sliding speed is varied and there is not much effect in the wear loss, it is shown in Fig. 11b. Then, for a similar load and the speed of sliding 2.16 m/s with a different distance, the wear loss is found to be increased, and it is presented in Fig. 11c.

When the interaction between the parameters is considered for wear loss for sisal fiber-reinforced composite, the sliding speed increases from minimum to maximum concerning load and increases the wear rate. When the distance of sliding is increased from lower to a higher one concerning the increase in load, the wear rate is found to be increased only at maximum distance. Similarly, the distance increases from low to high concerning speed; the wear loss shows only little effect. From the interaction graphs, the trend of applied load concerning sliding distance and sliding speed shows

**Fig. 10** Typical wear track image of applied load and co-efficient of friction with time for Sisal fiber reinforced composite specimen



useful variations for the difference in minimum and maximum values of all the factors considered.

Similarly, the other response, COF concerning load, speed, and distance for sisal fiber-reinforced composite is obtained. When the rate is at 2.16 m/s and the sisal pin is made to travel at a 2000 m for various load conditions, the COF is increasing at a higher rate, shown in Fig. 12a. When 19.62 N of the load is applied for the same sisal fiber-reinforced composite pin for a sliding distance of 2000 m and the sliding speed is varied there is not much effect in the coefficient of friction, it is shown in Fig. 12b. Then, for the same load of 19.62 N and 2.16 m/s with the difference in sliding distance, the coefficient of friction is observed to be minimum, and it is presented in Fig. 12c. Here, the high volume of the coefficient of friction is noted for load, then for speed, and finally, it tends to reduce concerning distance.

When the interaction between the parameters is considered for the coefficient of friction for sisal fiber-reinforced composite, that when the sliding speed increases and the coefficient of friction is found to be minimum, and it decreases for maximum speed concerning the changes of load. Then, when the sliding distance is increased from lower to a higher one for a constant sliding speed concerning variations of load, the COF is found to be higher for minimum distance and lower for maximum length

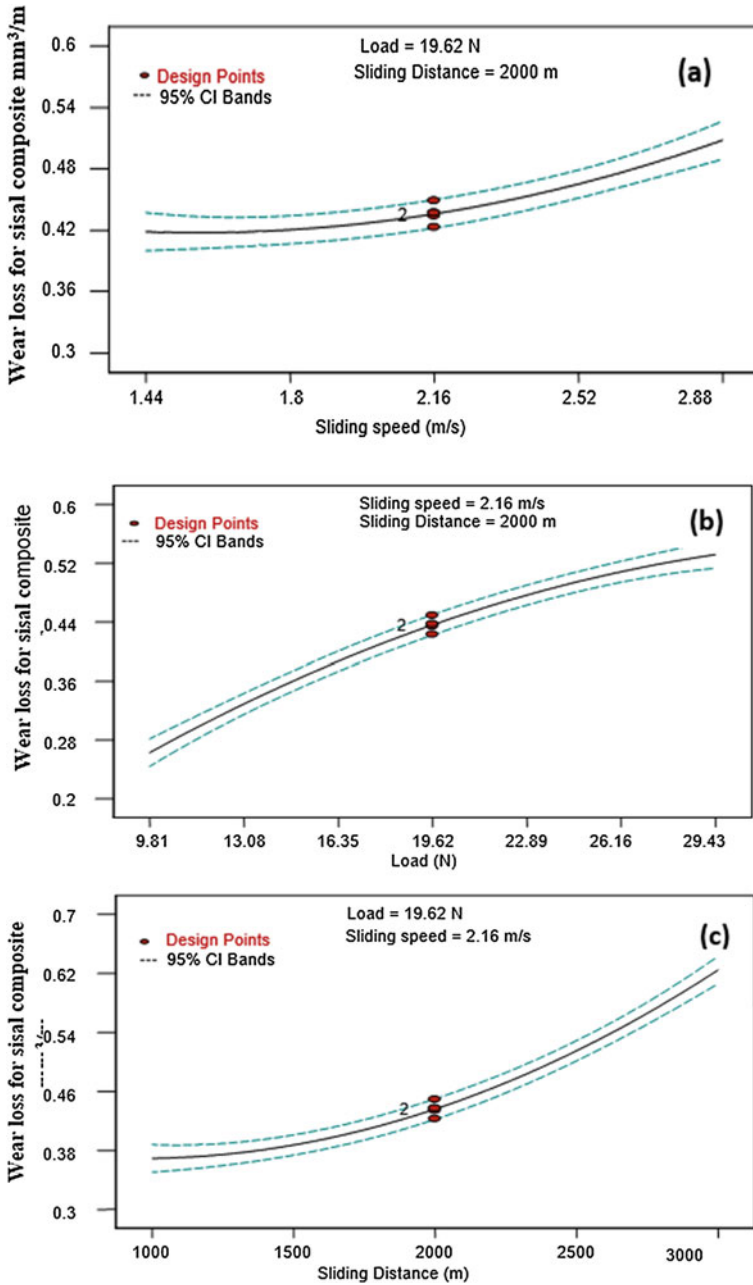
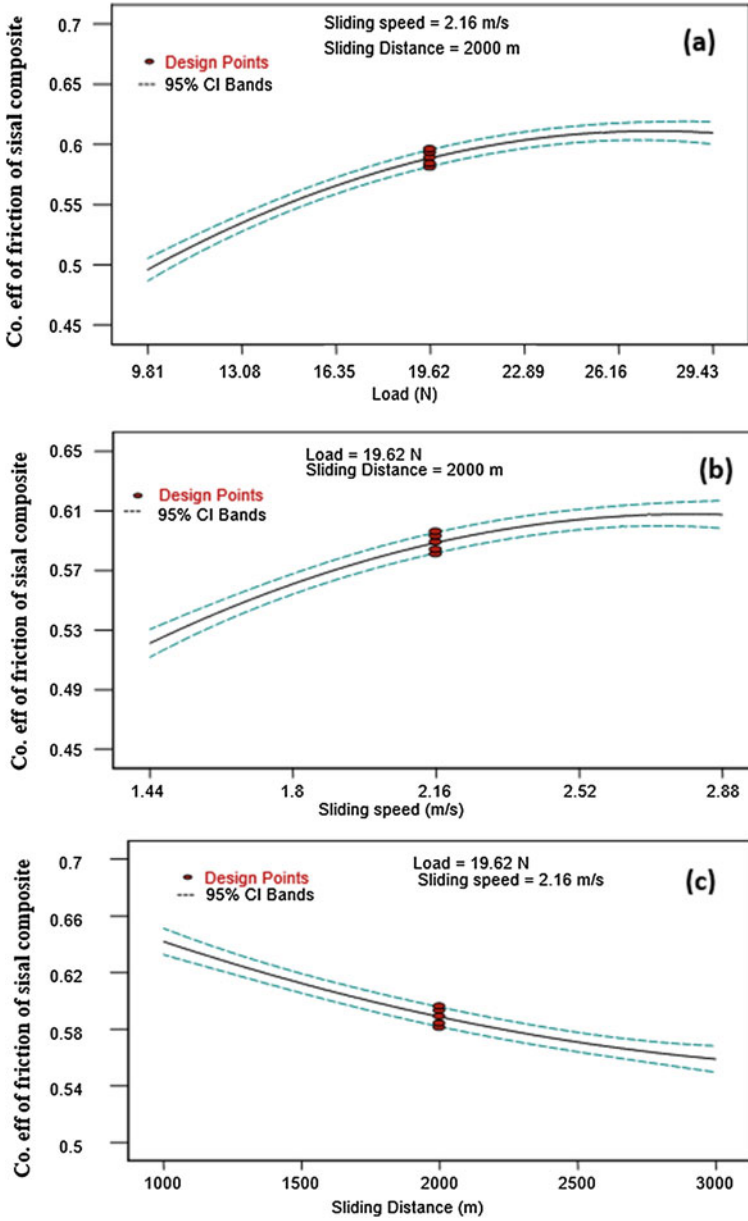


Fig. 11 Effect of wear loss for sisal fiber reinforced composites with respect to different parameters



**Fig. 12** Effect of Coefficient of friction of sisal fiber reinforced composites with respect to different parameters



traveled. Similarly, when the distance is increased concerning speed, the coefficient of friction shows high variation. It is observed, from the initial stage, that there is a good variation in the coefficient of friction of sisal fiber-reinforced composite when the load is varied for different speeds concerning distance travel of 2000 m. It is observed that, when the load increases, the coefficient of friction increases.

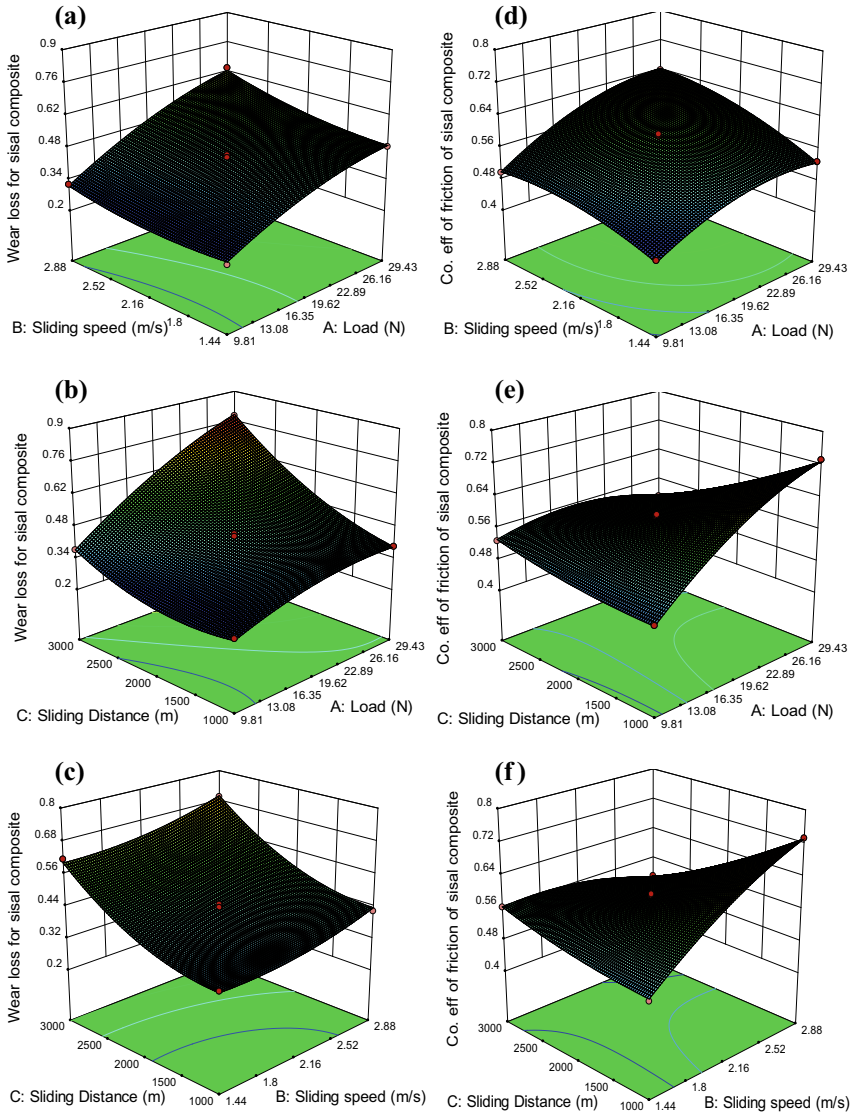
The distance is varied concerning different loads for the minimum distance and the coefficient of friction is found to be increased. For maximum distance, the coefficient of friction is found to be decreased. Similarly, for various sliding speeds concerning different sliding distances and considering the applied load as constant and is 19.62 N, the COF observed is maximum for minimum distance and maximum for maximum distance.

The 3D response graph is also generated for the variation of parameters, W, N, and S regarding wear loss and COF for the sisal composite pin specimen. Here, in the 3D graph, a clear view of the wear loss is seen. It is found to increase by the variation of load, and it is presented in Fig. 13a. When the load is increased the concerning distance and the wear loss is maximum, and it is observed in the mesh by a change in red color, and it is presented in Fig. 13b. Wear loss is found to be minimum for change in sliding speed and increases concerning distance, and is indicated in Fig. 13c. Similarly, the 3D response bgraph is also generated for COF regarding the applied load, sliding distance, and sliding speed. It shows a precise observation that the coefficient of friction decreases when sliding speed and load are made to increase. It is maximum when load and distance have increased, and it is represented in Figs. 13d–f.

Sisal fiber composite is observed to have minimum wear resistance property. This is due to the toughness of the fiber. So, it can be suggested to be utilized in moderate applications such as clutch pads, brake pads, and leaf springs. Wear mechanisms in polymer composites are said to be adhesive, abrasive, and fatigue wear. On a smooth surface, usually, adhesive wear occurs. In hard or rough surfaces, abrasive and fatigue wear will appear [20]. The mechanisms observed mostly are the delamination of fiber and micro plowing. The wear loss gets increased by scaling of distance, due to the consistent material removal. The orientation of fiber makes the difference in wear mechanism, and the recommended one is a normal orientation towards rubbing direction. Based on the natural fiber matrix selected, the wear and friction get varied based on the volume fraction of fibers and applied load. Typically, the wear increased concerning the increase of fiber content.

Sisal fiber-reinforced composite specimen after wear testing indicates that there is an increase in depth of penetration on the matrix in the wear track. As well, the fibers also get protruded out on the wear track from the different magnification factors of images. This observation indicates that wear takes place not only for the matrix but also for fiber. Micro pits are developed on the worn area because of the adhesive action of pins and composites applied load [21–23].

Due to adhesion, the matrix fiber detaches from the surface which results in wear track on the composite. In some locales, fragile epoxy resin has been confined because of high weight and plastic distortion, and after that, flotsam and jetsam are made. It



**Fig. 13** Three D response graph for wear loss and Coefficient of friction for sisal fiber reinforced composites

is inferred from the results that natural strands are viable to improve the tribological properties.

## 5 Conclusions

- The investigation aims to find a replacement for synthetic fibers in composites. There has been limited study on woven sisal reinforcements. In this investigation, the tribological behavior of sisal composites is carried out.
- Modeling is carried out for wear experiments by statistical analysis using Box-Behnken design.
- The analysis of the results is carried out for the tested specimen using SEM,
- Studies on natural fiber have drastically increased because of its essential properties and environmental adaptability. Wear is determined for sisal fiber-reinforced composites.
- The model developed for predicting the considered responses is fit. Wear tracks, damaged fibers, and matrices are studied through the SEM analysis for the sisal fiber-reinforced composite pins. Ultimately, these composites reduce the adverse effect on the environment.
- The variables considered for the present investigations are only three. By considering more variables, the research is more robust.

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