The Impact of Nano Fly Ash Particulates on Tribological Performance of Jute /Cotton fiber Reinforced Hybrid Bio-composite

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Abstract: In this study hand layup technique was used to fabricate hybrid bio-composite based on jute and cotton fiber. Three different percentage of Nano fly ash was considered in the fabrication of the composite. The characteristics of the material removal from the surface of the developed composite in dry sliding conditions were investigated. The ASTM G-99 standards are used to perform a tribological study of hybrid composites. The dry sliding wear of developed Nano composite tested on pin-on-disc tribometer. To optimize the parameters, the Taughi statistical method is used for experiment design. Different applied loads were considered and scanning electron microscopy was used to examine the influence of the shear force on the interaction between fibers and resin after sliding at different loads. The outcome significantly contributes to the knowledge enhancement. In order to analyze statistical data one way ANOVA is implemented. The main findings of the work was that percentage of Nano fly ash particulates significantly influence the wear and frictional performance of jute and cotton fiber reinforced epoxy based hybrid bio-composites. In dry sliding conditions, sliding velocity was second most significant factor which influences the running in and steady state wear behaviour of the formed composites. The composite's wear resistance was found to be higher with 3 percent Nano fly ash particulates than with others. Jute and cotton fiber hybridization gave promising results to replace synthetic fibers in light weight structural applications at same operating conditions.

Keywords: Nano Fly Ash; Wear, Tribology; Hybrid bio-composites; Taughi; Optimization.

1. Introduction

Global demand, Light weight, environmental friendliness, low cost and biodegradability are some suitable feasibility criteria for composites. Hybrid bio composites with nano particulates not only partially fulfill those requirements but also find increasing applications in furniture, sports accessories, aviation and automotive industries. Presence of nano particles, Drapability on multiply curved surfaces, improved mechanical and wear peculiarities, high strength to weight ratio and cost reduction make them viable solution in current demand of composite materials[1-2]. Nature, constituents and effectiveness of bonds between matrix and fibers, volume fraction, reinforcement nature, orientation, type of nano particulates and size of particulates are several factors on which mechanical and wear peculiarities of hybrid bio composites with nano particulates depend[3-4]. Despite the good mechanical peculiarities of (jute/cotton) natural fibers poor adhesion and wetability lead to composites whose properties are low as compared to synthetic fiber composites. Hybridization can solve these drawbacks using nano particulates[5-6].

In hybrid bio composites biodegradable components obtained from nature in present work jute and cotton obtained from waste i.e. from packaging and textile. In hybrid bio-composites combination of reinforcement selected in such a way that they inherently possess different properties of each component. This approach results in better final bio-composites that was earlier limited by the properties of single reinforcement only.

Hybridization also provides wider window and helps investigate the feasibility of recycling or reusing cotton and jute fabric textile wastes as reinforcement, which generally end up in landfills. Cotton, polyester, and jute are currently the most commonly used fibers in the textile and apparel industries, and as a result, every household generates large quantities of cotton and jute waste on a daily basis during processing and after use. While recycling textile waste fabrics becomes problematic especially separation challenges. As a result, novel recycling methods are required to deal with these forms of textile wastes.

Textile waste, such as cotton and jute fabrics, is preferred as reinforcement because of its inherent qualities of low cost and high strength. Recent studies have discovered that natural jute fiber-filled polymer composites have a higher wear resistance[19-21)]. In the shipbuilding industry, jute fiber reinforced polymer composites, as well as cotton fiber reinforced polymer composites, are widely used[34)].

Considering the wear, structural, thermal, and insulation properties of waste cotton and jute fiber, this study looked into the feasibility of producing hybrid composites with improved wear characteristics from post-consumer waste textile waste. Soil contamination, also known as land fill, is a major problem in today's to opt different combinations of reinforcements for desired set of properties. Bio-composite, with two or more reinforcements in single matrix known as hybrid bio-composite. Reinforcements maybe present in different physical forms like fiber with other fibers, fibers with particulates fillers, layered fibrous mats, two different particulate fillers etc. The hybridization effect and high performing fibers, such as fibers like Kevlar, Banana, sisal, jute, carbon and basalt widely studied but biodegradable reinforcement based hybrid bio composite explored to a lesser extent. Researchers applied natural fibers and fillers in combination or synthetic fibers and fillers in combination[7-8)]. Very few researchers have studied where both the reinforcing phases consists of biodegradable fibers with particulate fillers[x y].

1.1 Jute and cotton textile waste as reinforcement material.

World in population and improved living standards increased to textile consumption globally. Fashion trends and high rate of consumption creates bigger impact on textile production and their wastes[18)]. Waste management in textiles paid little or no attention on post consumer based wastes. Post consumer waste includes after sewing operation waste, rejected fabrics, used fabrics, and cutting waste. Volume of production increases as demand increases, and waste fabrics managing become an alarming issue in the different parts of world. Improper waste management and continuous land filing creates environmental decay. Therefore, it is is crucial to develop textile waste recycling solutions. This work aimed to world, as it has an impact on human health, the environment, and quality of life. As a result, in recent years, sustainable composites technologies have received a lot of attention as part of the sustainable growth and green material agendas[31-39)]. Furthermore, waste-derived composites made from textile waste fibers are known as a low-cost, sustainable alternative to conventional or synthetic materials[31-32)]. By transforming waste into usable resources like composites, it also helps to minimize waste disposal, landfills, and environmental pollution.

1.2 Nano Fly ash particulates as filler

High energy demand in modern industries relies on coal combustion in thermal power plants to fulfill the energy requirements. Fly ash is a light weight waste produced due to coal combustion at thermal power plants. India faces problem of safe disposal and recycling of fly ash at various levels which significantly influenced by different physical properties like shape, size, density porosity etc[12-13)]. Resin is very expensive if used in pure form. Fillers are added to the resin firstly to control cost and secondly to improve mechanical, chemical, and physical properties. Industrial wastes like Fly ash solve problems of exploring cheaper filler materials. Most of industrial wastes are buried and landfills, which is costly and cause environmental hazards. It is evident from the characteristics of fly ash wastes that they have good potential for utilization in developing composites[14-15)]. Fly ash provides enhanced mechanical and wears properties like toughness, durability, elastic modulus etc. It has properties of better surface finish, dimensional stability, weight reduction and non toxic. However, little has been reported about its ability as a filler material in hybrid composites at the nanoscale[z-x].

In present work jute and cotton natural fibers (textile waste) as reinforcements and Nano-fly ash particulates (thermal power plant waste) as filler and epoxy resin taken as matrix utilized to prepare hybrid bio-composites and tribological peculiarities were analyzed by varying the nano fly ash particulates fillers percentage 1,2 and 3% respectively.

2. Experimentation/Materials and Methods

2.1Matrix and Reinforcement Materials

In current study epoxy resin is used due to very common industrial usage and multi functional application. Aradlite LY 556 i.e. epoxy resin of density 1.2g/cc and HY951 hardener of density 0.96g/cc mixed in a ratio of 1:10 supplied from Shakshi Chemical Pvt. ltd. New Delhi. Wastes cotton fiber and Waste jute fiber (i.e. after customer usage) collected at locally and Nano fly ash purchased from Nanoshel Private limited, Panchkula, India.The average size of nano particles was 90 nanometer.

2.2 Sample fabrication

Different samples for testing were fabricated by hand lay-up technique. Developed samples/ laminates were prepared of 300×300×6 mm^3 size or dimensions with total four plies maintained at 6 mm thickness for wear testing and three different kinds of formulation were shown in figure 2 below.

In all composites samples all layer of woven fiber either textile or packaging waste is at 0° angle with base and then the epoxy resin is applied after placing each layer of fabrics, equally distributed by using brushes and roller is used to compress at normal temperature pressure 50 kN compression weight is applied for 24 hrs at normal temperature and pressure.

Table 1. Sample designation and their composition

S. No.	Sample Designation	Nano composition
1	HW1	Jute +Cotton Fiber with 1% Nano fly ash
2	HW2	Jute +Cotton Fiber with 2% Nano fly ash
3	HW3	Jute +Cotton Fiber with 3% Nano fly ash

2.3 Density and void fraction measurement

One of the most common defects during sample preparation is voids, which results in low resistance to water penetration and poor composite strength. Composites with 1% voids are good composites and 5% voids are poorly made composites.

Equation below was used to calculate the theoretical densities of the composites.

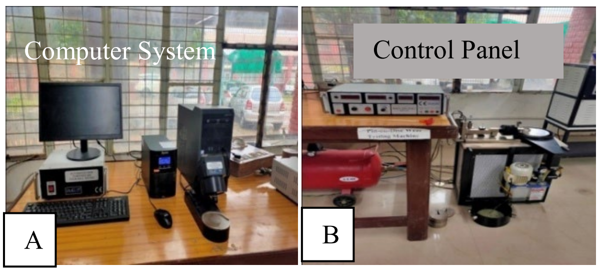
$$\rho_{ct} = \frac{1}{\left[\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}\right]} \ldots\ldots\ldots\ldots(1)$$

On the other hand actual densities of the developed composites were measured using a water immersion method (using distilled water) for individual sample average eight value s of density were observed as per ASTM D2734-94.

2.4 Wear testing machine

The tribometer pin on disc type as shown in Figures 1 A,B,C,D were used to analyzing COF and wear rate as output responses. The ASTM G-99 standards are used by the company make DUCOM. To communicate smoothly during operations, the tribometer was attached to a computer system.

In this type of tribometer pin was mounted on disc with the help of lever which is facilitated with normal load and speed variations. The whole setup along with control panel facilitates to observe wear and coefficient of friction under dry conditions. Each composite sample was made in the form of pin shape of 10 mm thickness and 30 mm length.



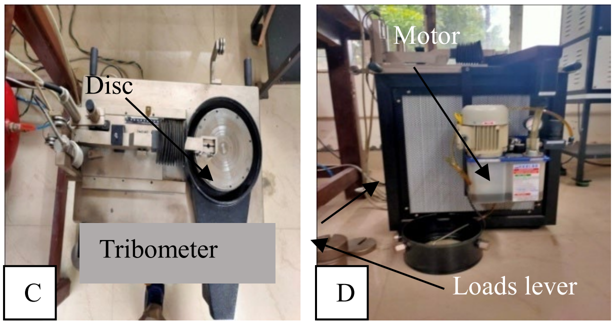


Fig.1. Tribometer pin on disc: DUCOM make (A) System attached to pin on disc tribometer. (B)Control Panel of pin on(C) Top view of pin on disc tribometer. (D) Front view of pin on disc tribometer.

Fig.2 Developed hybrid composites

During the experiments, the pin was held in place by a holder connected to a crank lever mechanism. The disc as counter material EN31 having roughness RA 1.21(Hardness HRC 65) rotates against the pin shaped composite samples. All the tests were performed on different Disc track diameter (vary from 20mm – 140mm). A weight balance is used to assess the weight of the developed composites samples before and after the wear test. The normal load was varied from (10-50 N) different weights with supporting arrangements to maintain the normal load via the machine's LVDT sensor. Sliding velocity range varied from (1-5m/s) by using control panel. The wear rate (WR) of one of the output responses was determined using the following weight loss formula:

$$WR = \Delta m / \rho\, d \qquad (1)$$

Where Δm represents the weight loss in grams, d represents the sliding distance in meters and ρ is the density of composites developed. COF directly obtained from computer system.

3 Results and Discussion

3.1 Micro-structural studies

The microstructure of developed composites observed using Digital tool maker microscope.

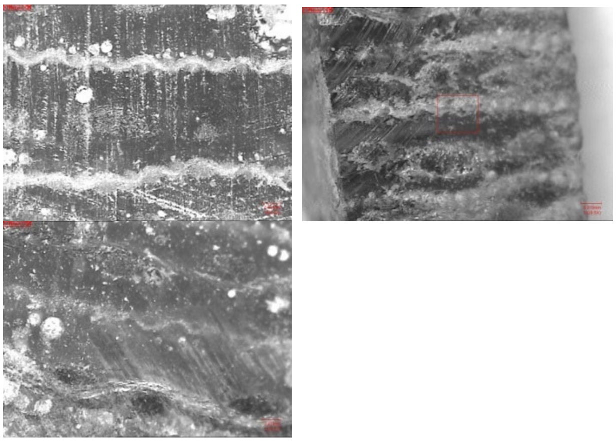


Fig. 3 (A) Composite Sample with 1% Nano Fly ash at 1000 µm (B) Composite Sample with 2% Nano Fly Ash at 1000 µm (C) Composite Sample with 3% Fly ash at 1000 µm

3.2 Effect of Nano Fly Ash on COF and wear rate under steady state conditions

Effect of Nano fly ash on COF and wear rate is examined with respect to sliding velocity, normal load, and sliding distance. COF and wear rate of developed composites is studied on tribometer (pin on disc type), by sliding the fabricated Nano composites specimen against the steel (EN31) counterface. Parameter range experimented is tabulated in below table 2. Sliding velocity and Nano fly ash % directly related to wear rate and COF whereas sliding distance and normal load inversely related to wear rate and COF. It is also observed that nano fly ash with 3wt% are most effective filler for friction reduction in hybrid composites. A uniform dispersion of nano fly ash particles and matrix boding contribute towards improved tribological properties. The Coefficient of friction of the nano fly ash filled epoxy composites assumes an obvious decrease with particle content 3 wt%. The smallest coefficient of friction was observed with the combination of hybrid composite. Under dry sliding conditions inflation in normal load and sliding speed increases the temperature at the interface. It was supposed that the nano fly ash particles helped to strengthen the interface bonding between particles and the resin which contributed to increase in mechanical strengths and hence to increase in wear resistance. This indicates that the nano fly ash particles are very effective in reducing the wear rate of epoxy hybrid composites. Further SEM images i.e. Figure 4 (a)(b)(c) and Figure 5(a)(b) and (c) confirm these results and showing wear direction, micro cracks, wear debris and Nano fly ash characteristics in microscopic level before and after wear.

Table 2 Input parameters and their level

Parameters	**Notation**	**Level 1**	**Level 2**	**Level 3**
Normal Load (N)	NL	10	30	50
Sliding Distance (m)	SD	1000	3000	5000
Sliding Velocity(m/s)	SV	1.50	2.25	3
Nano Composition (%)	NC	1	2	3

3.3 Statistical Analysis

The Experiments using L27(4^3) Taughi orthogonal array design with four variables (i.e. normal load, sliding velocity, sliding distance and Nano composition percentage) at three level to find COF and wear rate. The variables with their level and observations after experiments are shown in table 2 and table 3 respectively. Design of experiment was planned for creating quadratic models for wear rate with COF. Analysis of variance for both the output responses drawn in tabular form in table 3 and table 4 respectively. Based on ANOVA regression equations for wear rate and COF derived in table 5. Predicted values on software v/s confirmation experiments results shown in table 6.

Table 3 Experimental output responses at various level and combination of input parameters

	Normal load (N)	Sliding Velocity (m/s)	Sliding Distance (m)	NC%	WearRate×10^{-4} (mm^3/m	COF
1	10	1.50	1000	1	0.5	4.1
2	10	1.50	1000	1	0.49	4.2
3	10	1.50	1000	1	0.48	4
4	10	2.25	3000	2	0.44	3.1
5	10	2.25	3000	2	0.43	3
6	10	2.25	3000	2	0.42	2.9
7	10	3	5000	3	0.39	1.6
8	10	3	5000	3	0.35	1.5
9	10	3	5000	3	0.34	1.8
10	30	1.50	3000	3	0.3	2.6
11	30	1.50	3000	3	0.32	2.5
12	30	1.50	3000	3	0.28	2.4
13	30	2.25	5000	1	0.52	3.8
14	30	2.25	5000	1	0.51	3.7
15	30	2.25	5000	1	0.5	3.6
16	30	3	1000	2	0.48	2.5
17	30	3	1000	2	0.45	2.8
18	30	3	1000	2	0.45	2.6
19	50	1.50	5000	2	0.41	3.5
20	50	1.50	5000	2	0.4	3.3
21	50	1.50	5000	2	0.39	3.2
22	50	2.25	1000	3	0.35	2.3
23	50	2.25	1000	3	0.34	2.2
24	50	2.25	1000	3	0.33	2
25	50	3	3000	1	0.52	3.5
26	50	3	3000	1	0.51	3.4
27	50	3	3000	1	0.52	3.3

Table 4 ANOVA for wear rate

Source	DF	Adj SS	Adj MS	F-Value	P-Value
NL	2	0.0141	0.00704	0.44	0.650
SV	2	2.5719	1.28593	80.74	0.000
SD	2	0.0363	0.01815	1.14	0.342
NC	2	12.0363	6.01815	377.88	0.000
Error	18	0.2867	0.01593		
Total	26	14.9452			

Table 5 ANOVA for COF

Source	DF	Adj SS	Adj MS	F-Value	P-Value
NL	2	0.000289	0.000144	0.70	0.511
SV	2	0.011400	0.005700	27.48	0.000
SD	2	0.001089	0.000544	2.63	0.100
NC	2	0.134289	0.061744	323.73	0.000
Error	18	0.003733	0.000207		
Total	26	0.150800			

Table 6 Regression equations for wear rate and COF

S. No.	Response	Regression equations (in terms of actual factors)
1	Wear Rate	2.9407 - 0.0296 NL_10 + 0.0037 NL_30 + 0.0259 NL_50+ 0.3704 SV_1.50 + 0.0148 SV_2.25 - 0.3852 SV_3.00+ 0.0259 SD_1000+ 0.0 259 SD_3000- 0.0519 SD_5000+ 0.7926 NC_1 + 0.0481 NC_2- 0.8407 NC_3
2	COF	0.42333+ 0.00333 NL_10+ 0.00111 NL_3 0- 0.00444 NL_50- 0.02667 SV_1.50 + 0.00333 SV_2.25+ 0.02333 SV_3.00+ 0 .00778 SD_1000- 0.00778 SD_3000+ 0.0 0000 SD_5000 + 0.08222 NC_1+ 0.00778 NC_2 - 0.09000 NC_3

Table 7 Results of the Confirmation Experiments for wear rate and COF

Njhb8Sr. No.	Response	Goal	Predicted (OA)	Experimenta (OB)	Error(%)= (OB-OA)/ OA×100
1	Wear Rate	Minimize	.33	.36	8.3
2	COF	Minimize	2	2.16	7.4

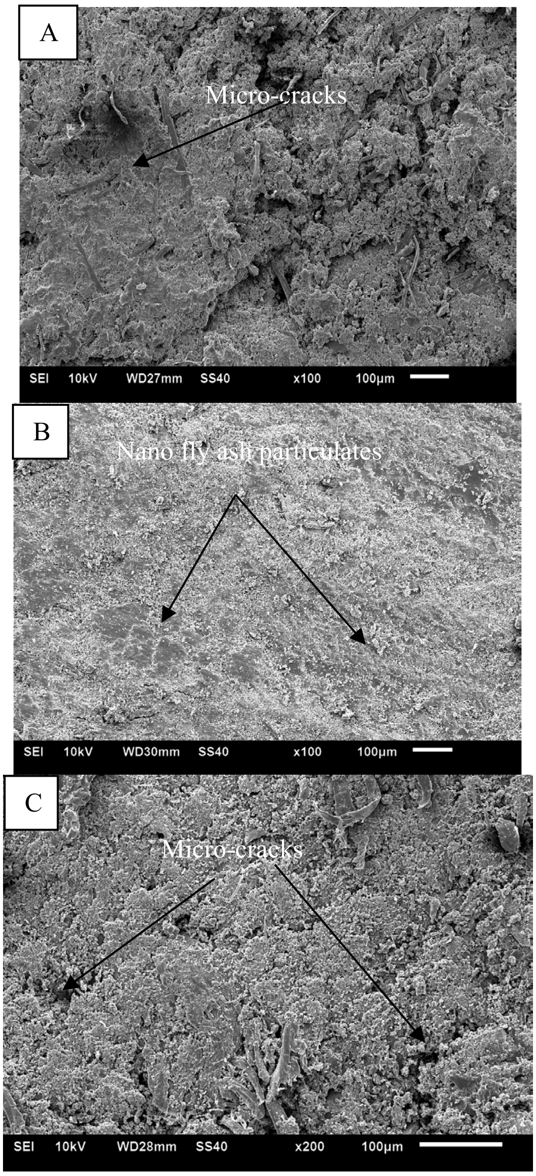


Fig.4 SEM images of developed hybrid Composites before wear at 100 μm (A) HW1 1% Nano fly ash (B) HW2 2% Nano fly ash (C) HW3 3% Nano fly ash.

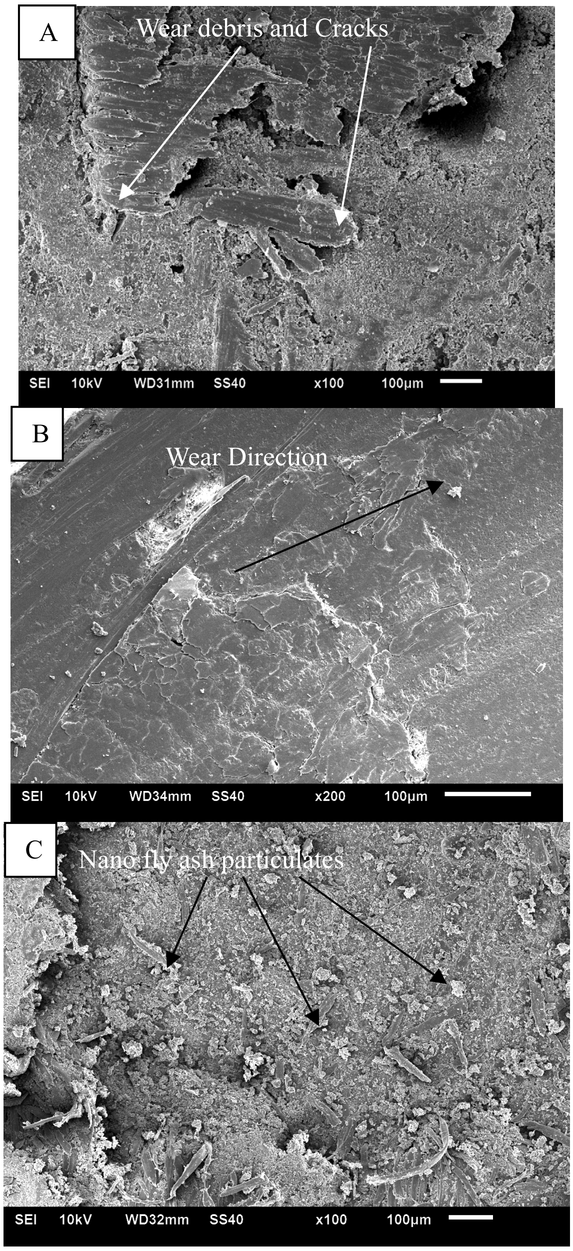


Fig. 5 SEM images of developed hybrid Composites after wear at 100 μm (A) HW1 with 1% Nano fly ash (B) HW2 2% Nano fly ash (C) HW3 3% Nano fly ash

4. Conclusion

In this work the fabrication of jute and cotton fiber reinforced epoxy hybrid bio-composites was explained. The tribological experimental data was reported for different percentage of Nano fly ash. The worn out surface observation was conducted by using SEM. The main findings of the work can be listed below:

1. Nano fly ash Percentage and sliding velocity are two most significant input parameters that influence on the wear and frictional performance of epoxy based hybrid bio-composites.

2. Sliding velocity control the running in and steady state wear behaviour of the developed composites in dry sliding conditions.
3. Wear resistance of the composites having 3% Nano fly ash found to be better compared to others.
4. Hybrid bio- fibers (jute + cotton) gave very promising results to replace synthetic fibers like glass from some applications at same operating conditions.
5. After conducting confirmation experiments an error of 8.3% for wear rate and 7.4% for COF respectively shows model is valid and adequate.
6. SEM images confirm wear out surfaces, delamination, wear direction and cracks.

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