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Mechanical and tribological analysis of jute, cotton reinforced epoxy based hybrid composites

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Abstract. Increase in environmental pollution and global warming due to continuous use of petroleum based materials, exploitation of forest reserves, improper industrial wastes management and natural resources. To reduces such alarming issues and find viable solutions, innovative research work on recycling of used materials such as used (clothes) textile wastes and used jute fibers has been reported to develop advanced sustainable hybrid composites in this work. The current study deals with mechanical and wear peculiarities of (cotton and jute fiber) textile wastes reinforced epoxy composites. Hand lay-up method was used to develop composites in five different stacking sequences. The developed composites were characterized for its mechanical peculiarities namely hardness, flexural, tensile, toughness, as per ASTM standards. Hybrid composite which was found with best sacking sequence, pure cotton and pure jute fiber composites were further analyzed for their wear peculiarity behaviour using Taughi (L27) design of experiment approach. Morphologies after mechanical and wear testing studies using SEM. It was inferred that hybrid composites with JCCJ stacking sequence produced good mechanical peculiarities. The currently developed composites have been found better than pure wood, epoxy, plastics and persuade for multifunctional applications.

Keywords: Epoxy Hybrid Composites, Waste jute fiber, Waste cotton fiber, Taughi design of experiment

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Introduction

Improved living standards and world population increased textile consumption globally during the last two and half decades. Rate of consumption and fashion trends creates bigger impact on textile production and their wastes [1-4]. Lack of recycling, absence of waste management strategies and continuous land filing creates environmental decay. Waste management in textile industry focus mainly towards post industry waste and little or no attention is paid to post consumer waste. Post consumer waste includes used fabrics, cutting waste, rejected and after sewing operation waste. As demand increases, volume of production increases, and waste fabrics managing become an alarming issue in the different parts of world. Moreover, post textile waste contributes to hazardous green house gases, groundwater contamination and even pollute environment. Degradable textile waste (non-organic) generates methane and (organic waste) like wool produces ammonia during decomposition. Non-degradable textile waste (synthetic) mostly accumulated in landfill, both contributes to environmental pollution and social alarming issues [5-8]. Firstly to minimizing such issues it is important to develop recycling solutions for textile waste and secondly textile waste must utilize as a resource. Therefore, it is important to develop recycling solutions for textile waste. This work aimed to investigate the feasibility of recycling cotton and jute fabric textile wastes, which are generally ended up in landfill. Currently, cotton and jute are globally used fibers in textile and apparel industry, and therefore during processing and after use every household produces massive amount of cotton and jute waste in daily basis. While recycling textile waste fabrics becomes problematic, especially separation challenges. Therefore, innovative recycling solutions required to develop during deal with such types of textile wastes [9-11].

Utilization of textile wastes in various applications in automobile segment, aerospace industry, and building construction, marine has become great research area of interest. Automobile and construction sector consumes significant/ amount of energy, materials, cost and various other resources therefore recycled, sustainable and cost-effective materials has capability to replace conventional materials. Global regulations of the countries trending and promoting recyclable, sustainable, cost-effective and eco-friendly construction and automotive materials. The main goal to use waste textile fibers in hybrid composites is to achieve improved strength, light weight, competitiveness and durability.

Textile waste i.e. cotton and jute fabrics are preferred due to their inherent features like low overall cost and better strength. It is observed that natural jute fiber filed polymer composites have particularly better wear resistance in the recent researches. Cotton fiber as well as jute fiber reinforced polymer composites are widely used in ship and automobile industries [12-14].

Previous researches reported the suitability of recycled textile fibers for building construction and automobile sector such as thermal, acoustic insulation, wear and structural reinforcement [15-18]. Considering the properties and characteristics of waste cotton and jute fiber due to superior wear, structural, thermal and insulation properties, this research investigated the feasibility of hybrid composites having better wear peculiarities developed from post consumer waste textile waste.

The mechanical and wear behaviour of materials depends on the factors such as matrix type, fiber type fiber size, stacking sequence, material thickness, density, porosity [19-21]. Mechanical properties of woven jute fabric hybrid and effect of hybridization and layering pattern were studied [6]. Jute fibers gave very promising results, wear resistance of composites found to be better in antiparallel orientation and fiber orientation has significant influence on wear and frictional performance of jute fiber reinforced epoxy composites [7]. The primary objective of this research work was to reuse and utilize waste cotton and jute fiber to develop a sustainable hybrid composite. The developed composites using textile waste would enhance the sustainability of the new product by replacing synthetic material up-to some extent [24-28]. No research work has been in the literature on hybrid composites of cotton waste fiber and used jute waste fiber in epoxy resin. The present work develops five kinds (different stacking sequence) of composites. Pure cotton waste fiber, pure jute waste fiber and hybrid composites (combination of cotton and jute with three different fiber orders). The incorporation of more than one reinforcing materials in a single matrix is called hybrid composites [29-34]. In current experimentation, mechanical peculiarities of all five different kinds of composites were tested. Further best among hybrid composites (three different fiber orders of composites), pure waste jute fiber and pure waste cotton fiber were tested for wear peculiarities. The effect of hybridization of waste cotton and waste jute layering pattern effect on mechanical peculiarities were observed. Coefficient of friction and wear rate are output responses during tribological analysis. Morphology of wear out and fractured composites examined to understand fiber matrix interaction in relation to mechanical and wear peculiarities.

Materials and Methods

Material Used in preparation. The stacking sequence and their designation of textile and packaging waste fibers shown in Fig. 1. Currently, epoxy resin is used due to very common industrial usage and multi functional application. Aradlite LY 556 i.e. epoxy resin of density 1.2 g/cc and HY951 hardener of density 0.96 g/cc mixed in a ratio of 1:10 supplied from shakshi chemical pvt. Ltd. New Delhi.

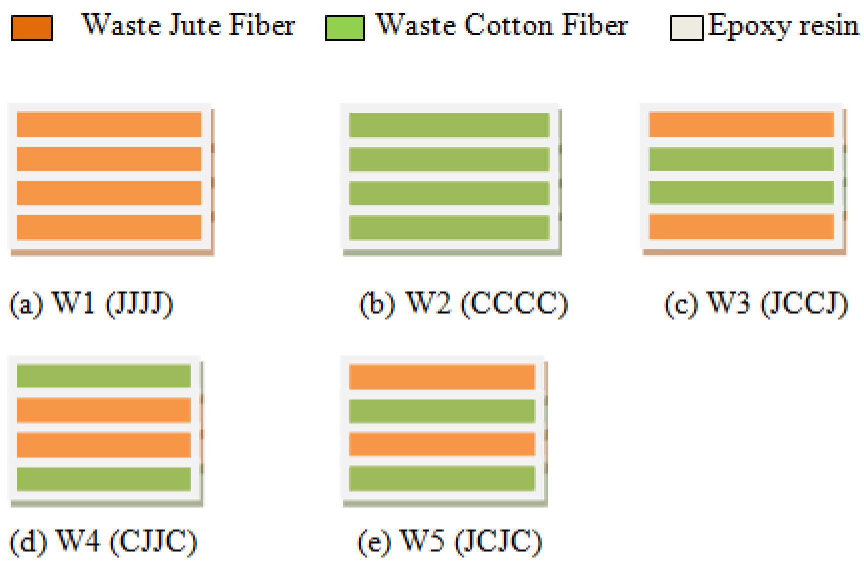

Fig. 1. Composites development with different Stacking sequence

Five different samples for testing were fabricated by hand lay-up technique, flow chart shown in Fig. 2. five different kinds of samples/ laminates were prepared using 300×300×3 mm^3 size or dimensions with total four plies maintained at 3 mm thickness for mechanical (tensile, flexural, impact and hardness) testing by varying the stacking sequence of textile and packaging waste fiber to obtain various composites. For wear testing, samples of 6 mm thickness were prepared.

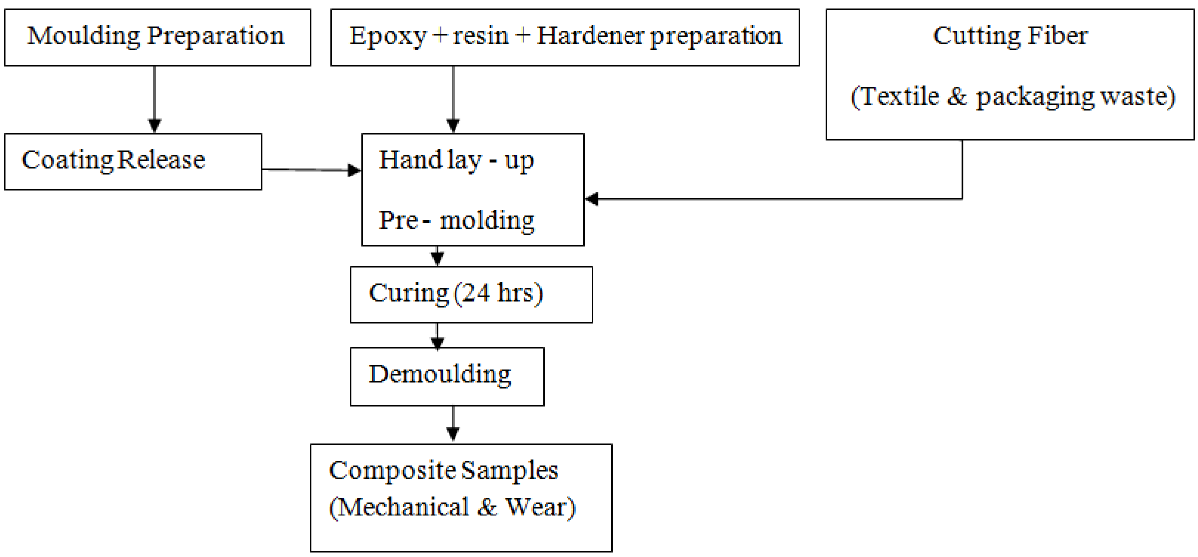

Fig. 2. Technique flow chart of composites by hand lay up

In all composites samples (Table 1) all layer of woven fiber either textile or packaging waste is at 0° angle and then the after placing each layer of fabrics epoxy resin is applied, equally distributed by using brush and roller to compress at normal temperature pressure. 50 kN compression weight is applied for 24 h at NTP.

Table 1. Sample designation and their architecture

S. No.	Sample Designation	Fiber Stacking sequence
1	W1(JJJJ)	Jute-Jute-Jute-Jute
2	W2(CCCC)	Cotton-Cotton-Cotton-Cotton
3	W3(JCCJ)	Jute-Cotton-Cotton-Jute
4	W4(CJJC)	Cotton-Jute-Jute-Cotton
5	W5(JCJC)	Jute-Cotton-Jute-Cotton

Weight fraction is calculated as below [13] reference:

$$W_f = \frac{W_f}{W_f + W_m}, \tag{1}$$

$$W_m = W_m\left(W_f + W_m\right), \tag{2}$$

where W_f = weight of fiber, W_p = weight of packaging waste fiber, W_t = weight of textile waste fiber, W_m = weight of matrix.

Total fiber volume fraction is calculated using following as[18]

$$V_f = \frac{\left(\frac{W_t}{\rho_t}\right)+\left(\frac{W_p}{\rho_p}\right)}{\left(\frac{W_t}{\rho_t}\right)+\left(\frac{W_p}{\rho_p}\right)+\left(\frac{W_m}{\rho_m}\right)}, \tag{3}$$

where ρ_m = density of matrix, ρ_t = density of textile fiber, ρ_p = density of packaging fiber.

Methods. After fabrication, the next step is to check mechanical and wear behaviour of formulations as per ASTM standards shown in Table 2 below. Which shows the different ASTM standards followed during the study to obtain an average value for each mechanical property, three identical specimens from each composite combination were evaluated.

Table 2. Shows ASTM standards followed during experimentation.

S. No.	Parameters under observation	ASTM Standard followed
1	Tensile Strength	ASTM D638-14
2	Flexural strength	ASTM D790-10
3	Toughness (Izod Impact test)	ASTM D256-10
4	Micro Hardness	ASTM D2240-05
5	Wear	ASTM G-99

Discussion and Results

Density and void fraction 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:

$$\rho_{ct} = \frac{1}{\left[\frac{W_f}{\rho_f}+\frac{W_m}{\rho_m}\right]}. \tag{4}$$

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 values of density were observed as per ASTM D2734-94.

The volume of void content (V_v) was calculated using

$$V_v = (\rho_{ct} - \rho_{ce})/\rho_{ct} \quad (5)$$

Voids remain the key cause of the disparity between experimental and theoretical densities. All composites have less than 3 % voids, which indicate that each laminate was good. By comparing pure textile and pure packaging waste, it was observed that hybridization of waste, i.e. packaging and textile, had less voids.

Tensile peculiarities. Five different kinds of composite samples are tested in UTM (at CIPET Baddi) for tensile properties, presented in Fig 3. The stress strain relationship is used to calculate the tensile strength and tensile modulus of laminates. All composites have a steady rise in tensile peculiarities, according to the findings, whereas W3 (JCCJ) stacking sequence type laminate shows significant improvement among all.

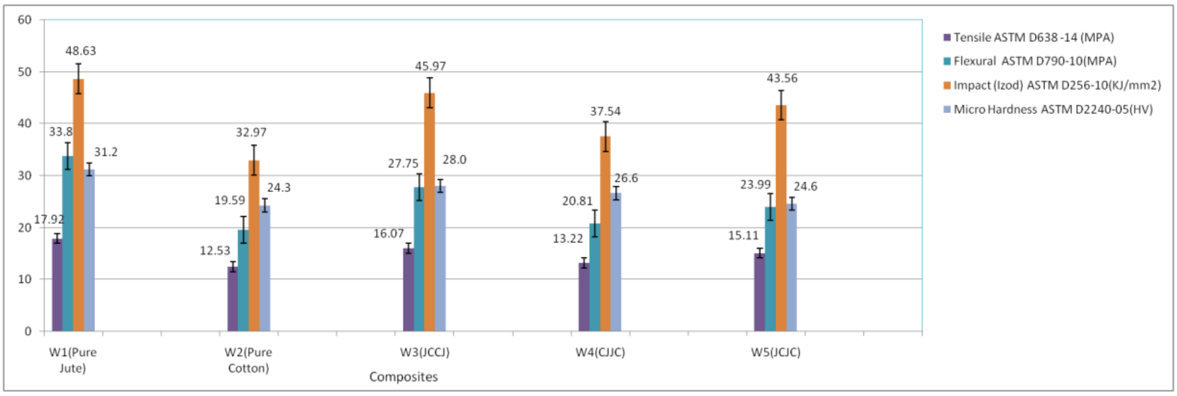

Fig. 3. Mechanical peculiarities of developed composites

Flexural peculiarities. The three-point bending test was used to investigate the flexural peculiarities of composite laminates. Fig.3 shows the flexural strength. W3 (JCCJ) composite was found to be higher respectively as far as the pure waste based composites fiber packaging waste based composites had a better flexural strength than waste textile composites laminates. The flexural power of the hybrid composites with the stacking series JCCJ are 27.75 MPa respectively. Flexural research reveals that the hybridization of two waste-based fibers improves flexural peculiarities as well. All of these findings show that the constituents of the hybrid and stacking sequence have an impact on flexural strength.

Impact peculiarities. Impact strength of developed composites using Izod test (at CIPET baddi) Fig. 3 shows toughness results. It is revels from results that impact strength i.e. toughness of the developed composites improved and among all the specimens W3 (JCCJ) found to be best stacking sequence and further recommended for wear or tribological testing.

Microhardness. Hardness of the developed composites using Vickers hardness test as per ASTM D2240-05 standards. Figure 3 shows results based on test average three tests on a particular composites were conducted from the results W3 (JCCJ) stacking sequence shows higher valve among other stacking sequence and hardness of all the developed composite laminates improved by hybridization and different stacking sequence.

Wear peculiarities. The tribometer pin on disc type was 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 running Winducom2010. 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 monitor wear and friction under dry conditions. The developed composites were evaluated under different parameters (Normal load, sliding distance, sliding velocity and composition type) for evaluation of wear rate and COF. Each composite sample was made in the form of pin shape of 30 mm length and 10 mm thickness.

Table 3 shows the input parameters for testing the composites. The size /dimensions of the specimen were 30×10 mm.

Table 3. Input parameters and their level

Parameters	Notation	Level 1	Level 2	Level 3
Normal Load (N)	NL	10	20	30
Sliding Distance (m)	SD	1500	3000	4500
Sliding Velocity(m/s)	SV	0.75	1.5	3
Composition Type	CT	TW	PW	HY

TW= Textile Cotton waste (W2 (CCCC)), PW = Packaging Jute Waste (W1 (JJJJ)), HY = Hybrid Composites W3(JCCJ).

The pin was held tightly with the holder attached with crank lever mechanism during tests. The disc of 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 20 mm – 140 mm). Before and after the wear test, a weight balance is used to determine the weight of the developed composites samples. The normal load was varied from (10-50 N) different weights with supporting arrangements to maintain the normal load through LVDT sensor attaches to the machine. Sliding velocity range varied from (1-5 m/s) by using control panel. One of the output response wear rate was calculated using weight loss formula given as:

$$WR = \Delta m/\rho\, d, \tag{6}$$

where Δm is weight loss in grams, d is sliding distance in meters and ρ is the density of developed composites. COF directly obtained from computer system with Winducom 2010 software.

To analyze the tribological behaviour of developed composites, Taughi L_{27} is used for design of experiments with responses shown in Table 4 and multi-way ANOVA was applied for optimization and analysis of variance shown in Table 5 and Table 6 for COF and wear rate.

Regression equation for wear rate and COF shown in Table 7 and Fig. 4 addressing relationship of responses COF and wear rate with input parameters sliding distance, sliding velocity and composition type in graphical manner. Whereas Table 8 gives the validation of given results in ideal conditions, i.e. observations of COF and wear rate after confirmation experiments.

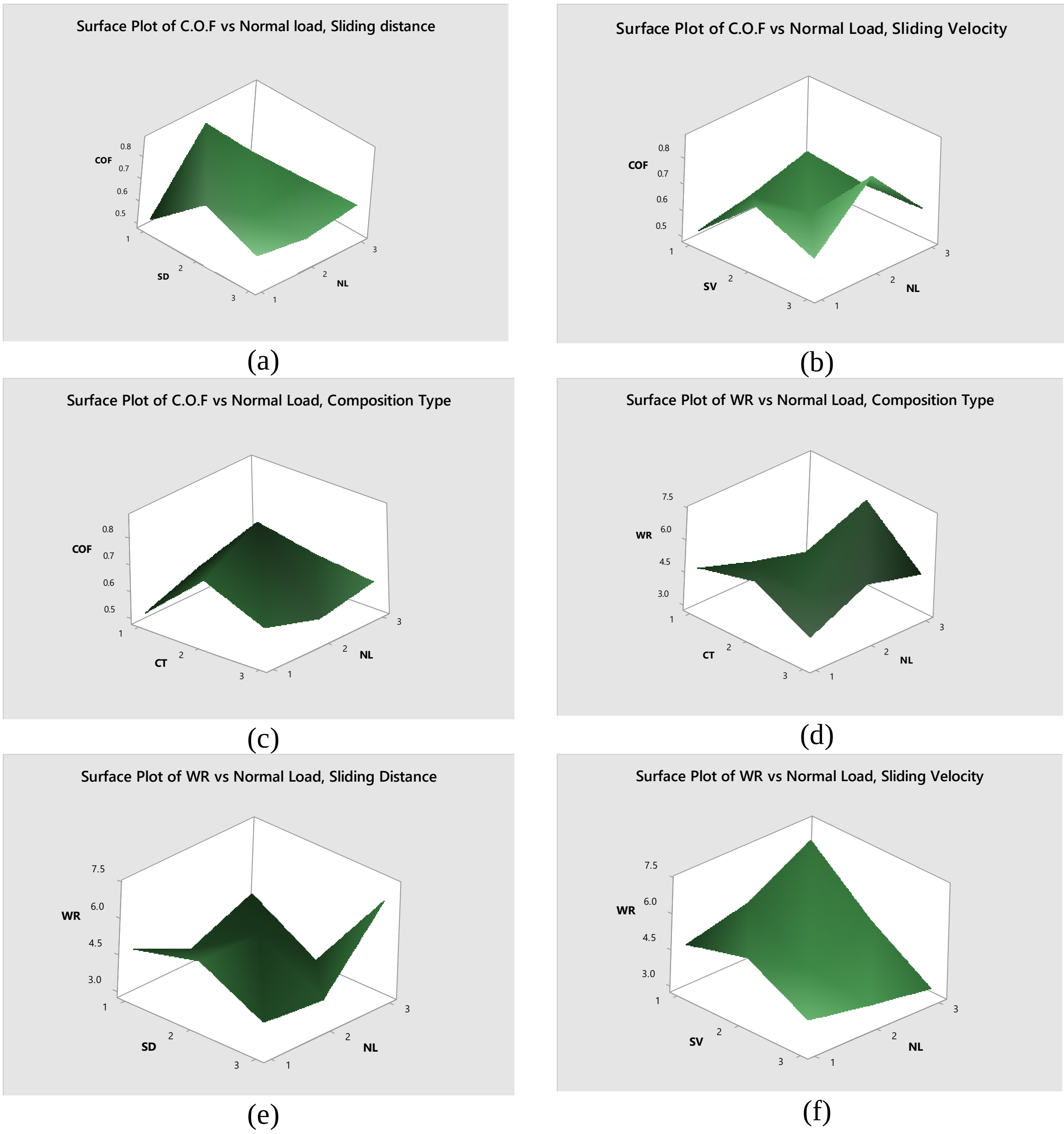

Fig. 4. Results: (a) relationship COF vs normal load;(b) sliding velocity relationship COF vs normal load; (c) sliding distance relationship COF vs normal load; (d) composition type relationship WR vs normal load;(e) composition type relationship WR vs normal load; (f) sliding distance relationship WR vs normal load, sliding velocity

Table 4. Experimental output responses at various level and combination of input parameters

S. No	Normal load N	Sliding Velocity, m/s	Sliding Distance, m	Compositi on Type	Wear Rate×10^{-4}, mm^3/m	COF
1	10	1	1500	TW	0.50	4.8
2	10	1	1500	TW	0.52	4.6
3	10	1	1500	TW	0.53	4.8
4	10	3	3000	PW	0.70	5.8
5	10	3	3000	PW	0.72	5.5
6	10	3	3000	PW	0.74	5.0
7	10	5	4500	HY	0.63	4.0
8	10	5	4500	HY	0.62	4.2
9	10	5	4500	HY	0.62	4.1
10	50	1	3000	HY	0.55	5.5
11	50	1	3000	HY	0.56	5.4
12	50	1	3000	HY	0.57	5.3
13	50	3	4500	TW	0.58	4.0
14	50	3	4500	TW	0.59	3.9
15	50	3	4500	TW	0.60	3.7
16	50	5	1500	PW	0.87	3.4
17	50	5	1500	PW	0.85	3.6
18	50	5	1500	PW	0.80	3.8
19	80	1	4500	PW	0.60	7.0
20	80	1	4500	PW	0.65	6.9
21	80	1	4500	PW	0.63	6.7
22	80	3	1500	HY	0.59	4.8
23	80	3	1500	HY	0.60	4.8
24	80	3	1500	HY	0.61	4.6
25	80	5	3000	TW	0.61	3.3
26	80	5	3000	TW	0.62	3.2
27	80	5	3000	TW	0.60	3.0

Table 5. ANOVA for COF

Source	DF	Adj SS	Adj MS	F-Value	P-value
NL	2	0.013652	0.006826	20.48	0.000
SV	2	0.068763	0.034381	103.14	0.000
SD	2	0.006852	0.003426	10.28	0.001
CT	2	0.129341	0.064670	194.01	0.000
Error	18	0.006000	0.000333		
Lack of fit	3	2.3634	0.7878	22.16	0.00
Pure Error	18	0.6400	0.0356		
Total	26	0.224607			

Table 6. ANOVA for wear rate

Source	DF	Adj SS	Adj MS	F-Value	P-value
NL	2	0.1250	0.1250	.87	0.360
SV	2	18.2688	18.2688	127.74	0.000
SD	2	1.5606	1.5606	10.91	0.003
CT	2	8.6489	4.3244	30.24	0.000
Error	18	3.0034	0.1430		
Lack of fit	3	2.3634	0.7878	22.16	0.00
Pure Error	18	0.6400	0.0356		
Total	26	31.6067			

Table 7. Responses for wear rate and COF

S. No.	Response	Regression equations (in terms of actual factors)
1	Wear Rate	4.6556+ 0.1000* NL_10- 0.3667* NL_50+ 0.2667 *NL_80+ 1.0111 *SV_1+ 0.0222 *SV_3 1.0333* SV_5-0.3000 *SD_1500+ 0.0111* SD_3000+ 0.2889 *SD_4500- 0.7333 *CT_TW+ 0.6444 *CT_PW + 0.0889 *CT_HY
2	COF	0.63185- 0.01185* NL_10+ 0.03148* NL_50- 0.01963* NL_80+0.06407 *SV_1 + 0.00481 *SV_3+ 0.05926 *SV_5 + 0.02037 *SD_1500 - 0.00185 *SD_3000 - 0.01852 *SD_4500 - 0.05963 *CT_TW+ 0.09704 *CT_PW - 0.03741 *CT_HY

Table 8. Results of the Confirmation Experiments for wear rate and COF

Sr. No.	Response	Goal	Predicted (O_A)	Experimental (O_B)	Error (%) $(O_B-O_A)/O_A\times100$
1	Wear Rate	Minimize	0.62	0.66	6.4
2	COF	Minimize	4.2	4.4	4.7

SEM. Morphology of different composites after testing at different conditions was studied. Interfacial properties such as fiber/matrix interaction, void material, and fiber pull out of composites are all highlighted by morphology as shown in Fig. 5 below.

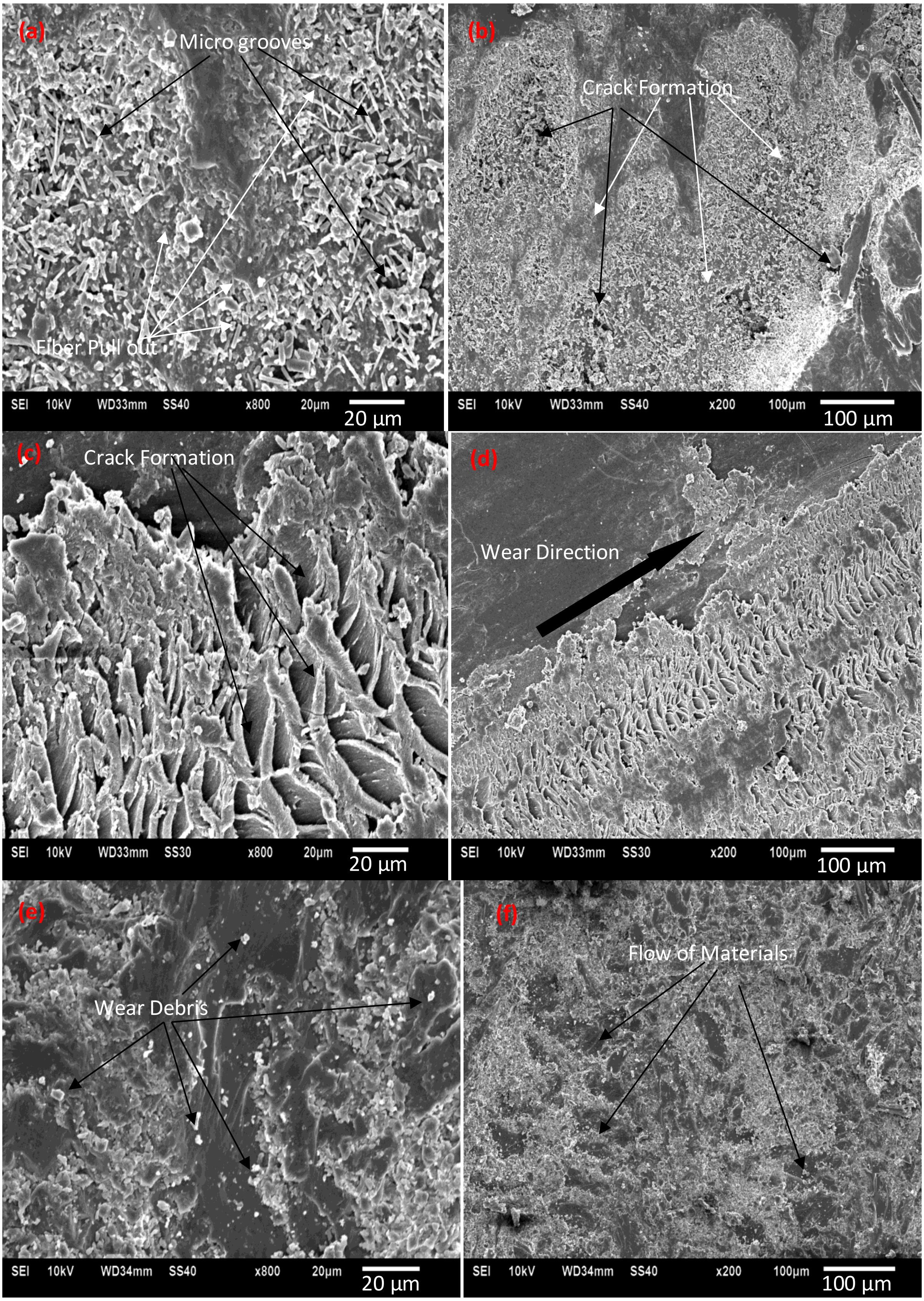

Fig. 5. SEM images of developed composites after wear: hybrid W3 (JCCJ) at 20 μm (a) and at 100 μm (b); packaging waste W1(JJJJ) at 20 μm (c) and at 100 μm (d); textile waste W2(CCCC) at 20 μm (d) and at 100 μm (e)

Conclusion

The cotton fiber waste and jute fiber waste are good reinforcing material, and they can be successfully used with epoxy to produce hybrid composite of different stacking sequence. The produced composites were characterized in mechanical peculiarities by flexural, tensile, impact, hardness tests further pure cotton waste and pure jute waste fiber and best combination of stacking sequence were tested for wear peculiarities using Taughi (L_{27}) design of experiment. SEM was used to study fractured and wears out surfaces. The results based on experiments are listed below.

1. The inclusion of an outer layer of waste jute fiber resulted in increased durability, ultimate tensile strength, and hardness, as well as improved adhesion between the matrix and the cotton fiber waste.
2. The presence of waste jute fiber in the middle increased the flexural strength of the central layer of jute and the outer layer of waste cotton fiber. The fractography studies showed that there were no cracks, indicating that the flexural strength was increased.
3. Above findings shows waste jute fiber at outside and intermittent layer of waste cotton fiber were best in case of mechanical peculiarities.
4. The morphological study is done through a SEM. The fiber pullout from composites, stacking of fibers, cracks, delaminated flacks, wear direction, crater and wear out surfaces in the composites were observed.
5. Sliding velocity and composition type are two most significant parameters for both the output responses (wear rate and coefficient of friction). The ANOVA tests confirmed the significance of generated models.
6. Present experimentation reveals that the placing of fiber or stacking sequence in the composites plays an important role in obtaining good mechanical peculiarities. Thus, it can be concluded that reuse of waste cotton and waste jute fibers is an effective way to utilize resources that is of low cost and its application also increases when compared to synthetic fiber.
7. Taughi method was used to optimize input parameters to reduce output responses. Both the wear and the coefficient of friction responses of composites are represented by significant quadric models. Taughi's three-dimensional diagrams also support the findings of the steady-state experiment. The R square value for wear rate and coefficient of friction is greater than 0.94, indicating that the model is significant.
8. Confirmation checks are used to double-check the results by using the same input parameters that were used to measure the expected value. Since the error percentage is 6.4 % and 4.7 % in S/N ratio of Wear rate & COF indicates that the model is adequate.
9. Waste Jute fiber and cotton fiber showed promise as replacements for synthetic fibers like glass, basalt for same composites at same operating conditions.

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