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PROCESSING, MECHANICAL CHARATERIZATION AND ITS TRIBOLOGICAL STUDY OF DISCONTINOUSLY REINFORCED CARYOTA URENS FIBRE POLYESTER COMPOSITES

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ABSTRACT

The awareness in plant fiber-reinforced polyester composite materials is increasingly emerging in manufacturing applications and vital exploration. They are inexpensive, absolutely or somewhat biodegradable and recyclable. Plants fibers from sisal, kenaf, pineapple, ramie, bamboo, flax, cotton, hemp, jute and banana has been mostly used as the reinforcement for composites due to its unique properties such as obtainability, renewability, low density and price used for the manufacturing of composites. The plant fiber composites are more environmentally friendly and are used in wide variety of applications such as transportation, military, building construction and packaging. In this presented paper processing, mechanical characterization and its tribological study of new class of Caryota Urens fiber reinforced with Polyester composites has been processed and investigated.

Keywords: mechanical characterization, two body abrasive wear, three body abrasive wear, design of experiments, discontinuously reinforced caryota urens fiber polyester composites.

INTRODUCTION

Caryota Urens belonging to the Palmae is a lofty handsome plain, distributed in forests of India. Caryota Urens is a leaf fiber that can be spun into thread and rope. Figure-1 shows the classification of plant fibers.
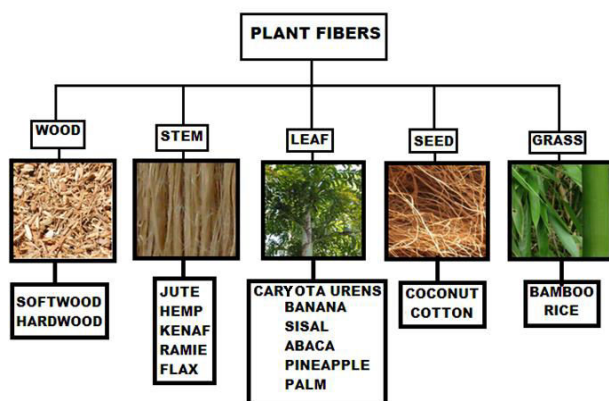
Figure-1. Classification of plant fibers.

From past 30 years composite materials have been the leading as developing materials due to its ultimate material properties and wide variety of applications. Today green technology has been the new era to improve the environmental quality of a number of products. Hence maximum attention is focused on plant fiber popularly known as natural fiber composites by several researchers [1-22].

Harish *et al.* [15] developed coir /epoxy and compared with glass fibers. mechanical properties of these materials have also been investigated. Wang and Huang [16] also studied on coir fiber and characteristics of these fibers has been analyzed. Nilza *et al.* [17] carried out research on three Jamaican natural cellulosic fibers. They carried out mechanical characterization study. Passipoularidis *et al.* and Rao *et al.* [18-19] fabricated lightweight composites using natural fibers and polymeric matrix.

Caryota Urens fibers has been considered as new class of natural fiber and there has been limited research carried out in this materials. Hence this present paper mainly focuses on influence of different fiber volume percentage of Caryota Urens fibers on the microstructure and mechanical property of Caryota Urens based polyester composites will be investigated in the present work. The microstructure has been studied using Trinocular inverted Metallurgical Microscope, mechanical property such as surface hardness has been studied using Vickers hardness tester and two body and three body wear behavior has been studied using Pin on Disc wear testing machine and abrasive wear testing machine.

EXPERIMENTAL

The materials used in the specimen for fabricating composite specimen are Caryota Urens (Figure-2) and polyester. The Caryota Urens fibers with a diameter of 8 microns and thickness of 0.2 mm are collected from Manipal, Udupi District, Karnataka, India. Polyester resin of density of 1.1 g/cm^3 and viscosity of 700 Centipoise along with catalyst methyl ethyl ketone peroxide and accelerator cobalt napthanate was purchased from M/s Ash Polymer Ltd., Bangalore. The DRCUFP composite laminates are fabricated by using stir casting technique for fiber Vol%. Initially, the fibers are dried in a muffle furnace at 600 ^{o}C for more than 5 hours before composite processing to remove moisture content. The matrix resin impregnated fiber stock is post cured for about 24 hours at 80 °C (Figure-3).

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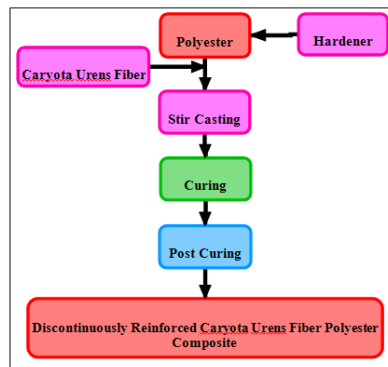
Figure-2. Caryota urens fiber.

Figure-3. Schematic representation of the manufacturing process.

Vickers hardness

Vickers hardness was measured using Matsuzawa micro-hardness (MMT-X7A; Matsuzawa Co., Ltd. Japan) testing machine with an indentation load of 100 gm allowing dwell time of 15 seconds for indentation. At least five indentations were taken for each specimen, and the average value was reported for Vickers hardness for DRCUFP composite specimens. Initially DRCUFP composites with fibre Volume percentage of 0%, 5%, 10%, 15%, 20%, 25% and 30% were fabricated using stir casting technique. After getting the Micro hardness of DRCUFP composite specimen three samples 0%, 10% and 20% were selected for further experimentation. Figure-4 shows the micro hardness of DRCUFP composites under different fibre Volume percentage.Figure-5 shows the Vickers indentation hardness tester.
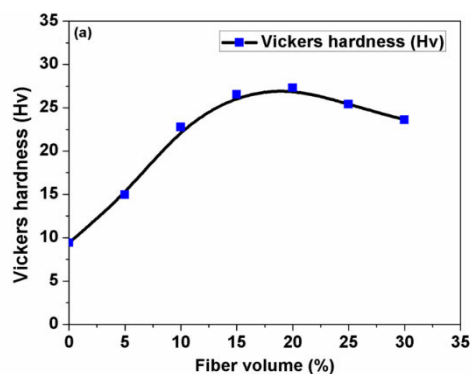

Figure-4. Micro hardness of DRCUFP composites under different fibre volume percentage.

Figure-5. Vickers indentation hardness tester.

Tensile, flexural and interlaminar properties of DRCUFP composites

The Tensile, Flexural and Interlaminar properties of DRCUFP composites specimens were measured using Universal Testing Machine (UTM, Instron 3366). Tensile testing of the specimen used in the experimental work is shown in Figure-6(a). The three point bending technique is used for measuring the flexural properties of the specimens as shown in Figure-6(b). The interlaminar shear strength (ILSS) is investigated according to ASTM: D 2344 (short beam shear test method) using UTM is shown in Figure-6(c). The density of of DRCUFP composite specimens were measured as per ASTM: D792-0 using displacement method. Figure-7(a-c) shows the experimental set up for measuring tensile, flexural and interlaminar shear strength.
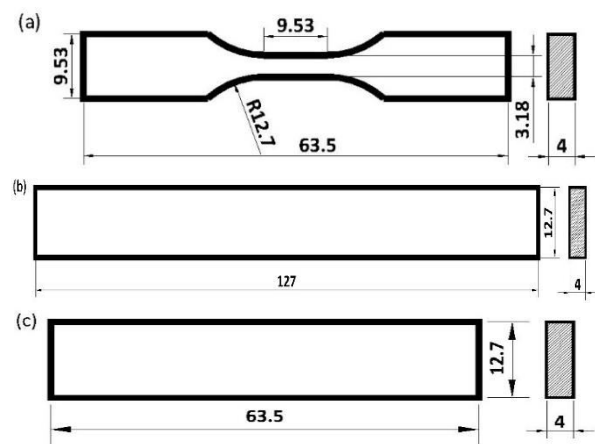
All dimensions are in mm

Figure-6. Schematic representation of (a) tensile (b) flexural and (c) interlaminar test specimen.
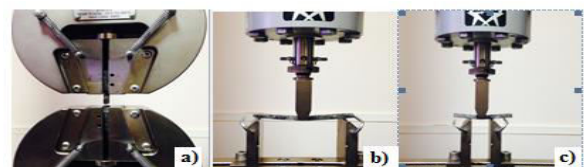

Figure-7. Universal testing machines for measuring (a) tensile(b) flexural and (c) interlaminar shear strength.

Scanning electron microscopy

Microstructure of fabricated materials of required sample size of DRCUFP composites are examined using Scanning Electron Microscope (SEM) {Model: JSM-6380LA, JEOL, Japan}(Figure-8). Similarly the fracture surface of the specimen used for tensile testing are also examined using SEM.
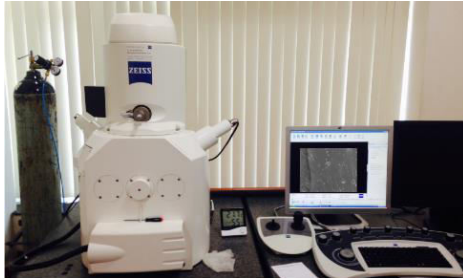

Figure-8. Scanning electron microscopy.

Moisture absorption test

Moisture absorption was conducted in accordance with ASTM D570-98. Three specimens of 64mm x 12.7mm were dried in an oven at 600℃ and then were allowed to cool to room temperature. The specimens were subjected to water environment and weighed regularly from 10-80 hrs with a gap of 10hrs.

Two body wear testing

Two body wear tests for the work piece 0 vol%, 10 vol% and 20 vol% as shown in Figure-9 were carried out by pin on disc wear testing machine illustrated in Figure-10(a). The pin material was DRCUFP composites. The disc material was EN-31 steel with a hardness of 640 H_v. The pin specimens were square of 8 mm and a height of 30 mm. The disc specimens were cylinders with an outer diameter of 100mm and a thickness of 8mm. The difference in the mass measured before and after the test gives the wear of the specimen.

Figure-9. Work piece for two body wear testing
a) 0 vol% b) 10 vol% c) 20 vol%.

DRCUFP composites having fibre volume percentage of 0%, 10%, 20% under different Load (L/N), Sliding Speed (m/s) and Sliding Distance (D/m) based on Taguchi's design of experiments as shown in Table-1. Micro structural analysis of worn specimen was done using Trinocular inverted Metallurgical microscope Figure-10(b).

Table-1. Levels and factors for two body abrasive testing.

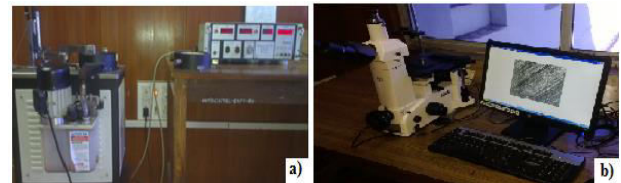| Levels	Fibre (Vol %)	Load (L/N)	Sliding speed (m/s)	Sliding distance (D/m)
1	0	9.81	1.67	1500
2	10	19.6	2.51	5250
3	20	39.2	3.35	9000

Figure-10.a) Experimental setup for wear test on Pinon discb) Trinocular inverted Metallurgical Microscope.

Three body abrasive wear testing

Initially, DRCUFP composites with fiber volume percentages of 0%, 10% and 20% were fabricated using stir casting technique. Followed by three body abrasive wear analysis on abrasive wear tester under different Load (kg), Number of turns and Speed (rpm) parameters at constant grain size of 5 microns and flow rate of 350 gm/min based on Taguchi's design of experiments. Levels And Factors for three body abrasive Testing is shown in Table-2. The test specimens were rectangular bar of size 7.6 cm x 2.5 cm x 1.3 cm as shown in Figure-11. The difference in the mass was measured before and after the test gave the abrasive wear of the specimen. The mass of the specimen was measured in an electronic weighing machine with a least count of 0.001gm to attain the possible accuracy. The ratio of mass lost was defined as the abrasive wear rate.Figure-12 shows the Dry Abrasion Tester used for experimentation.

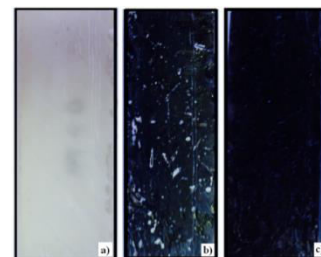**Figure-11.**Work piece for three body wear testing
a)0 vol% b) 10 vol% c) 20 vol%.

Table-2. Levels and factors for three body abrasive testing.

Levels	Load (N)	Number of turns	Speed(RPM)	Vol. (%)
1	19.62	20	100	0
2	39.24	30	150	10
3	58.86	40	200	20

Figure-12. Dry abrasion tester.

DESIGN OF EXPERIMENTS

Design of experiments (DOE) is an efficient technique for planning experiments to analyse and conclude the objective. The analysis is made using the popular software specifically used for design of experiment applications known as MINITAB 15 [23-29].

Taguchi's method

Taguchi techniques have been used widely used by various researchers since it has become a powerful and efficient tool to obtain optimal results by minimum sets of experiments. Further depending on the number of factors, interactions and their level, an orthogonal array will be selected. Taguchi has used Signal-Noise [S/N] ratio as the quality characteristic of choice. In case of two body abrasive wear and three body abrasive wear since there should be minimum wear under selected condition the smaller is the best characteristic has been selected and is given by equation below.

Smaller is the best characteristic.

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

RESULT AND DISCUSSIONS

Currently, many investigations are on to determine the usage of DRCUFP composites. It has become a potential material to replace metals for many parts. However, fabrication of DRCUFP composites, characterization and secondary processing operation such as drilling poses some challenges when compared to metals. Hence this paper deals with development of Discontinuously Reinforced Caryota Urens Fiber Polyester Composite (DRCUFP) composite and Mechanical characterization of DRCUFP composites such as micro hardness, Tensile, Flexural, Interlaminar shear strength, Moisture absorption, Two body Wear testing and three body wear testing.

Mechanical characterization

This section presents the Mechanical characterization of DRCUFP composites fabricated for the present investigation. Details of processing of these composites and the tests conducted on them have been described in the previous chapter. Experimentally obtained mechanical properties of DRCUFP composites have been studied and discussed. The SEM images of the test specimens of DRCUFP composites are shown in Figure-13(a, c).
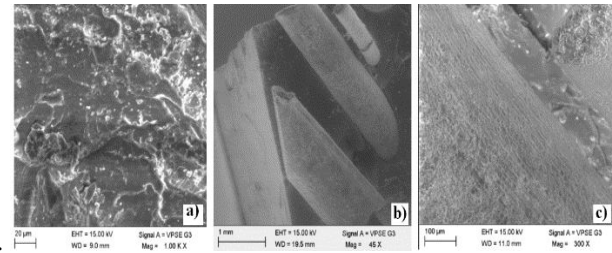
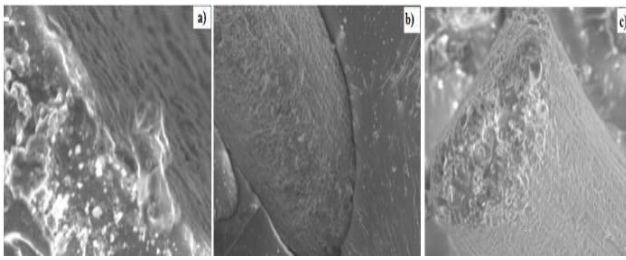**Figure-13.** SEM images of DRCUFP composites
a) 0 vol% b) 10 vol% c) 20 vol%.

Vickers hardness, Tensile, flexural and interlaminar properties of DRCUFP composites

The experimental values of mechanical properties of 0 fiber vol%, 10 fiber vol%, and 20 fiber vol% composites are presented in Table-3. From Table-3, it is observed that 20 fiber vol% DRCUFP composite has higher tensile strength as well as flexural strength as compared to 0 fiber vol%, 10 fiber vol% DRCUFP composite. This clearly indicates that 20 fiber vol% DRCUFP composite has highest load bearing capacity and the ability to withstand bending. The experimental values of mechanical properties of DRCUFP composites are presented in Table-3.

Table-3. Mechanical properties of DRCUFP composite laminates.

Fiber(Vol. %)	0	10	20
Density (gm/cm^3)	1±0.1	1.26±0.1	1.3±0.1
Vickers Hardness (H$_v$)	9.42±0.5	22.75±0.5	27.3±0.5
Young's modulus (GPa)	3.9±0.25	5.4±0.25	8.3±0.25
Tensile strength at break (MPa)	86.98±0.2	200.3±0.2	355.6±0.2
Flexural Strength (MPa)	26.9±2.5	43.18±2.5	78.87±2.5
Interlaminar Shear Strength (MPa)	7.13±0.5	10.31±0.3	13.13±0.3

Figure-14 (a,c) shows the SEM images of fracture surface of 0 fiber vol%, 10 fiber vol%, 20 fiber vol% composites after tensile strain vertical on the fiber orientation. From Figure-14 (a,c), it is observed that the crack opens up due to the tensile stress and the matrix deforms.
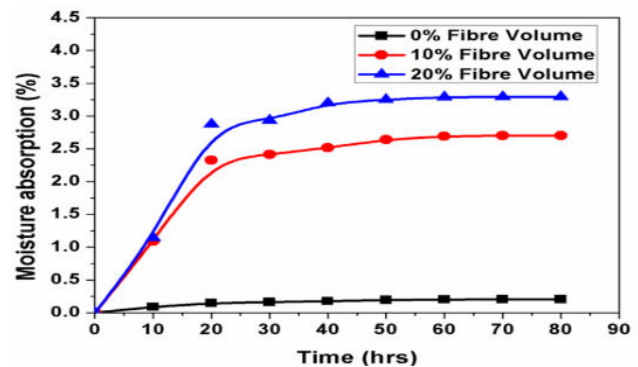
Figure-14.SEM images of fracture surface of DRCUFP composites.0 vol% b) 10 vol% c) 20 vol%.

Figure-15. Variation of moisture absorption of the DRCUFP composites with immersion time
a) 0 vol% b) 10 vol% c) 20 vol%.

Moisture absorption behaviour

Figure-15 shows the percentage of moisture absorption characteristics of 0 fiber vol%, 10 fiber vol%, and 20 fiber vol% DRCUFP composite samples in water environment for different time in hours. It is clear from the figure that the initial rate of moisture absorption and the maximum moisture uptake increases for DRCUFP composite specimens as time increases. Moisture absorption is maximum for 20 fiber vol% DRCUFP composite for 50 hours time period, having moisture absorption of 3.25%. It may be due to factors like porosity content, the lumen and fiber–matrix adhesion are somewhat responsible for the moisture absorption behavior of the DRCUFP composites.

Again it is observed that, the moisture absorption increases with immersion time, and got saturated after certain time period. Moisture absorption is not same for all the DRCUFP composites. The moisture absorption is approximately 2.5% for 10 fiber vol%, 0.25% for 0 fiber vol%, and 3.25% for 20 fiber vol%, DRCUFP composites. Fiber vol% also plays a significant role in moisture absorption process.
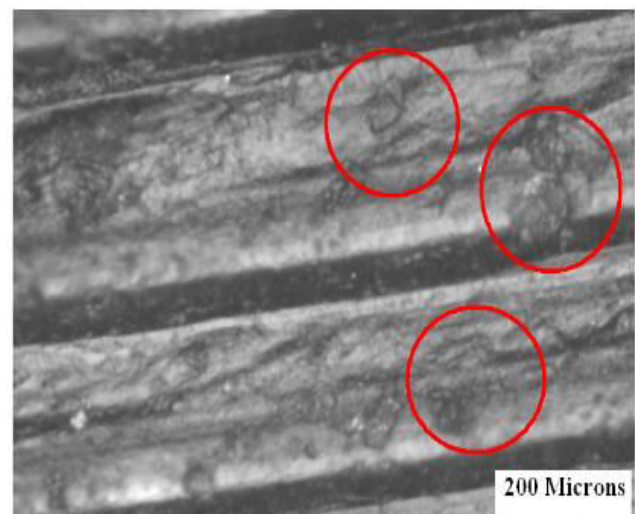
Two body wear performance of DRCUFP composites

Wear rate behavior of the DRCUFP composites under different wear conditions has been identified for different Load (L/N), Sliding Speed (m/s), Sliding Distance (D/m) and Fiber vol% using L_{27} orthogonal array to obtain optimum condition for wear.

The influence of loads on the abrasive wear rate of the 0 vol%, 10 vol%, 20 vol% DRCUFP composites, it has been observed that wear rate of all composite samples increases with load. This is because at higher load, the frictional thrust increases, which results in increased debonding, fiber pullout and fracture (Figure-16). It has also been observed that the abrasive wear rate decreases with addition of Caryota urens fiber up to 20vol% with minimum fiber pull out under all testing condition. Thus it can be conclude, addition of the Caryota urens fiber in polyester is very effective in improving its wear resistance.

Figure-16. Trinocular inverted metallurgical microscope image of DRCUFP composites worn out surface under high load.

Table-4. Analysis of variance for S/N ratio for two body wear.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
(A)Load (L/N)	2	163.749	163.749	81.8744	50.55	0.000	52.22
(B)Sliding Speed (m/s)	2	25.605	25.605	12.8024	7.90	0.021	8.16
(C)Sliding Distance (D/m)	2	10.519	10.519	5.2596	3.35	0.111	3.46
(D)Fiber (Vol. %)	2	109.292	109.292	54.646	33.74	0.001	34.85
(A)*(D)	4	2.468	2.468	0.617	0.38	0.815	0.39
(B)*(D)	4	4.170	4.170	1.0425	0.64	0.651	0.66
(C)*(D)	4	1.496	1.496	0.3739	0.23	0.911	0.26
Residual Error	6	9.719	9.719	1.6198			
Total	26	327.017					100

Table-5. Response table for signal to noise ratios for two body wear.

Level	Load (N)	Sliding speed (m/s)	Sliding Distance(D/m)	Fiber (Vol.%)
1	43.27	40.49	40.97	37.56
2	39.93	41.14	40.02	40.41
3	37.25	38.	39.45	42.47
Delta	6.02	2.46	1.51	4.91
Rank	1	3	4	2

From the analysis presence of less amount of wear is reported from the wear testing under 9.81 N load, Sliding Speed 2.51m/s, Sliding Distance 1500(D/m) and 20 fiber vol%. It is observed from wear analysis that, the wear failure is less in case of composites with higher fiber vol%. This is due to the fact that as fibres are harder phase in the composite more energy is required for the failure of the fibres.

From the main effects plot Figure-17. for wear indicates the selection of minimum Load (9.81N), lesser Sliding Distance (1500m), Sliding Speed (2.51m/s) and fiber vol%(20%) result the best combination to get lesser wear value for DRCUFP composites.

On the examination of the percentage of contribution (P %) of the different factors (Table-4), for wear it can be seen that Load (L/N) and Fibre (Vol %) has the highest contribution of about 52.22% and 34.85%. Thus Load (L/N) and Fibre (Vol %) is an important factor to be taken into consideration. It can be seen that Sliding Speed (P=8.17%), Sliding Distance (P=3.36%), and interactions neither present a statistical significance, nor a percentage of physical significance of contribution to the wear.

Table-5. Shows the ranking of each wear parameter using the Response Table for Signal to Noise Ratios (smaller is better) obtained for different parameter levels.
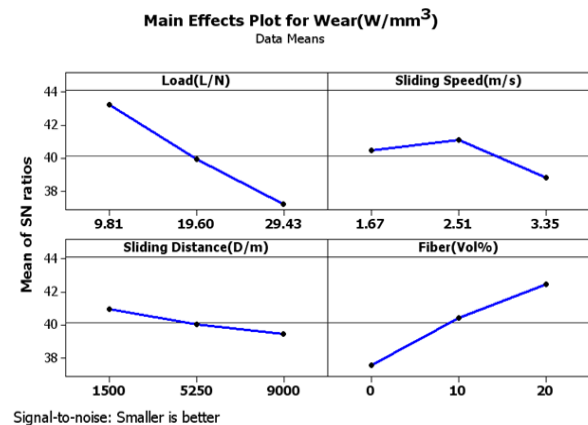
Figure-17. Mean S/N graph for two body wear.

Three body abrasive wear measurement of DRCUFP composite

The orthogonal array for three factors at four levels was used for the elaboration of the plan of experiments the array L_{27} was selected.

It is observed from the results that at higher volume (%), higher load and higher speed the wear rate of DRCUFP composite samples increases. This is because at higher load, the frictional thrust increases and at higher volume (%) debonding and fracture occurs.

From the main effects plot (Figure-18) for three body abrasive wear indicates the selection of less volume (10%), less load (2kg), less turns (20) and less speed

(100rpm) resulted in the best combination to get minimum abrasive wear value for DRCUFP composite.

On the examination of the percentage of contribution P (%) of the different factors for wear (Table-6), it can be seen that Speed (RPM) had the highest contribution of about 64.27%. Hence Speed is an important factor to be taken into consideration. It can be seen that Vol. % (P = 15.99%), Load (P = 8.33%), Number of turns (P = 7.16%) also contributed to the wear in their respective proportions. But, interactions between the various parameters, neither present a statistical significance, nor a percentage of physical significance of contribution to the wear respective proportions. But, interactions between the various parameters, neither present a statistical significance, nor a percentage of physical significance of contribution to the wear. Figure-19. Shows the Trinocular inverted metallurgical microscope images of worn surface under different Ratios (smaller is better) obtained for different parameter levels. Table-7 shows the ranking of each wear parameter using the Response Table for Signal to Noise.
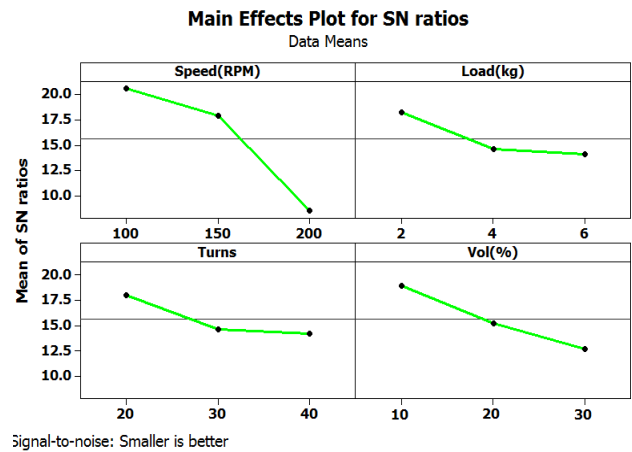
Figure-18. Mean S/N graph for wear.
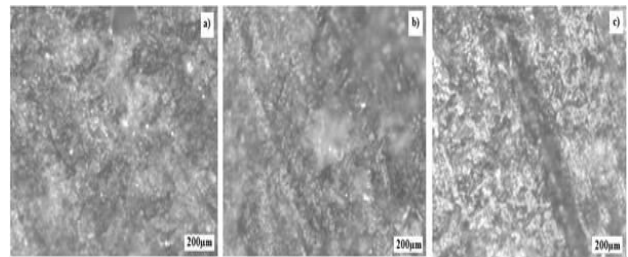
Figure-19. Trinocular inverted metallurgical microscope images of DRCUFP composites surface under different speed (a) 100rpm (b) 150 rpm (c) 200rpm.

Table-6. Analysis of variance for S/N ratiofor three body abrasive wear.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
(A)Speed (RPM)	2	718.94	718.94	359.468	26.65	0.001	64.27
(B)Load (kg)	2	93.16	93.16	46.580	3.45	0.100	8.33
(C)No. of Turns	2	80.18	80.18	40.089	2.97	0.127	7.16
(D)Vol. (%)	2	178.91	178.91	89.455	6.63	0.030	15.99
A X D	4	36.98	36.98	9.246	0.69	0.628	1.67
B X D	4	31.54	31.54	7.884	0.58	0.686	1.39
C X D	4	26.53	26.53	6.633	0.49	0.744	1.19
Residual Error	6	80.93	80.93	13.489			
Total	26	1247.16					100

Table-7. Response table for signal to noise ratiosfor three body abrasive wear.

Level	Speed(RPM)	Load(Kg)	No. of turns	Vol. (%)
1	20.553	18.261	18.073	18.984
2	17.875	14.577	14.651	15.244
3	8.516	14.106	14.221	12.717
Delta	12.037	4.155	3.851	6.266
Rank	1	3	4	2

CONCLUSIONS

Based on the results of the present research work, the following conclusions can be drawn for processing and characterization of Caryota urens fibre reinforced polyester composites:

- From the experimental values of mechanical properties for 0 fiber vol%, 10 fiber vol%,20 fiber vol% composites, it is observed that 20 fiber vol% DRCUFP composite has higher tensile strength as well as flexural strength as compared to 0 fiber vol%, 10 fiber vol% DRCUFP composite. This clearly indicates that 20 fiber vol% DRCUFP composite has highest load bearing capacity and the ability to withstand bending.
- It is observed that, moisture absorption is approximately 2.5% for 10 fiber vol%, 0.25% for 0 fiber vol%, and 3.25% for 20 fiber vol%, DRCUFP composites. Fiber vol% also plays a significant role in moisture absorption process.
- The influence of loads on the abrasive wear rate of the 0vol%, 10vol%, 20vol% DRCUFP composites, it has been observed that wear rate of all composite samples increases with load.
- Percentage of contribution P (%) of the different factors for wear it can be observed that Load (L/N) and Fibre (Vol %) has the highest contribution of about 52.28% and 34.90%.

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