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Investigation of Tribological Properties and Fabrication of Sisal Fiber Reinforced Polyester Composite

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Abstract—Present day researchers are highly inclined towards natural fiber as reinforcement for polymer ic composites. Natural fibers are eco-friendly in nature and have lesser environmental impact as compared to synthetic fiber. Apart from these natural fibers are low in cost and easily available. This paper presents an experimental study on the tribological properties of sisal fiber reinforced polyester composite. In the study the composites samples were fabricated using compression molding technique. The study was carried out using Taguchi approach by considering the four major parameters, which are fiber length, the weight fraction of fiber, the weight fraction of filler and wear test parameters (normal load for two body abrasive wear as well as for adhesive wear and impingement angle for erosive wear). Experimental results show that optimal combination of parameters for minimum erosive wearis 40mm fiber length, 25wt% fiber loading, 4 wt% filler volume and 300 impingement angle, for minimum two-body abrasive wear is 40mm fiber length, 25 wt% fiber loading, 6wt% filler volume and 30N normal load and for minimum adhesive wear is 40mm fiber length, 25wt% fiber loading, 6wt% filler volume and 10 N normal load. Variable renewable generation, such as wind and solar, is increasing worldwide and synchronous generation is displaced; the facility system frequency response and reliability are strongly challenged because these resources do not inherently contribute to the inertial response of the facility system. This paper demonstrates that both dynamic and continuous load control is in a position to supply a big portion of the anticipated need for inertia and fast frequency response required to integrate high level of renewable resources and to take care of power grid reliability.

Index Terms—Natural fiber, Sisal fiber, Erosive, Two body abrasive, Sliding Wear, Taguchi Method

I. INTRODUCTION

The frequent use of synthetic fibre as a reinforcement for polymer composite, all over the world has increased the environmental burden. For this reason, the development to natural fibre are in forced polymer composite is a subject to of enormous interest among researchers and scientist from both ecological and environmental perspectives. Nowadays natural fibres are being used in place of glass and other synthetic fibres due to many advantages such as low cost, low density, abundance, environmentally friendly, non-toxicity, high flexibility, renewability, biodegradability, relative non-abrasiveness, high specific strength and ease of processing [1-4]

Gupta and Shrivastva et al.[5] Investigate the wear and frictional properties of sisal fiber reinforced epoxy composite with the help of pin-on-disc (tribometer) wear testing technique. To make composite sheets they take sisal fiber about 30wt % as reinforcement and mixture of epoxy resin and hardener in the ratio of 10:1 by weight as a matrix. These composite sheets are fabricated by using hand layup technique. Then these composite sheets are tested on pin on disc machine to find out their friction and wear properties. These friction and wear properties were carried out at different operating conditions such as sliding speed (1-3 m/sec), sliding distance (1000m), applied load (10-30N). An experimental result shows that by increasing the applied load and sliding speed specific wear rate and coefficient of friction increases. Madhusudan and Kumar et al. [6] studied the wear resistance (2 body abrasive wear) behavior of sic powder. They prepare glass – sisal hybrid reinforced epoxy composite with different weight percent (0%, 5%, 10%) of graphitepowder.Then2bodyabrasiveweartesthadbeenperformedoncompositesheetsbypin-on-discmachinefor20Nloadandfordifferent sliding distance (25m, 50m, 75m). Then experimental results show that polymer composite with 10% graphite powder had least wear loss in compare to others. Suresha and Chandramohan et al. [7] studied the friction and wear behavior of sisal fiber epoxy composite with and without the filler material. Graphite Powder was taken as filler material. They prepare the composite sheets by adding 2.5% and 5% graphite powder in it and also by without adding filler material. These composite sheets were tested on increasing sliding distance at constant sliding velocity and applied load. Experimental results show that with wear rate increases with increasing sliding distance. Further results shows that coefficient of friction of Graphite powder filled composite is less in compare to graphite unfilled composite.

The aim of the study was to fabricate polyester based composites reinforced with randomly oriented short and long sisal fibers, to evaluate tribological properties such as abrasive wear, adhesive wear and erosive wear and to optimize the result using Taguchi analysis.

II. EXPERIMENTALDETAILS

Materials

In this study sisal fiber is used as reinforcement because of its low density, low cost, high tensile strength and elastic modulus in comparison to other natural fibers. This sisal fiber was obtained from Kovai Green Fibers, Coimbatore, Tamilnadu. Polyester Resin is used as matrix due to its low cost, dimensional stability, extreme flexibility in handling and excellent resistance to heat. Methyl ethyl ketone peroxide was used as hardener and graphite powder was used as a filler material due to its high wear resistance. Both resin and filler were obtained from local source. Properties of Sisal fiber are given in Table 1.

Table 1: Properties of Sisal Fiber [8-9]

Tensile Strength (MPa)	507 - 855
Stiffness/ Young's Modulus (GPa)	9.4 - 28
Density (g/cm^3)	1.3 – 1.5
Specific Tensile Strength (MPa/g cm^{-3})	362 - 610
Specific Young's Modulus (GPa/g cm^{-3})	6.7 - 20
Cellulose	55-65%
Hemi-Cellulose	10-15%
Lignin	2-4%
Pectin	10-20 %
Water Soluble Materials	1-4%
Fat and Wax	0.15-0.3%
Ash	0.7-1.5%

Fabrication of Composites

Thelongsisalfiberswerefirstcleanedtoremovedustandotherparticlesbypressurizedwaterthendriedinsunlightfor24hours.After drying in sunlight fibers were cut according to requirement i.e. 20, 40, 60 mm and then arranged in random orientation. After that composites were made of composition of different fiber, resin and filler. Total number of 9 composite samples is made (**by using Taguchi Method)**. Table 2 shows different composition of composite samples. In this case polyester resin and corresponding hardener (methyl ethyl ketone peroxide) is mixed in ratio 10:1 by weight in all samples. A mold having dimension 300X300 mm is used for casting of composites. To prepare the composite first hand layup technique is used which follows the placement of fiber layer one over another with res in applied in between the layers. Are leas in gagent is also used for easy removal off in is hed product from the mold.The open sides of mold were sealed round the periphery by using suitable sealant. The composite was cured under required pressure (approx.15bar) for required time (approx.40minutes) at required temperature (approx.150degreecent.) using **compression molding machine.** Then prepared composite is removed from the mold and then samples from composite of required dimensions were cut by diamond cutter for tribological testing i.e. abrasive, adhesive, and erosive wear.

Figure 1: Compression Molding Machine

Table 2: Composition of Composite Samples

Composites	Compositions
S1	Polyester (63% wt) + 40 mm sisal fiber (35% wt) + Graphite (2% wt)
S2	Polyester (71% wt) + 40 mm sisal fiber (25% wt) + Graphite (4% wt)
S3	Polyester (76% wt) + 40 mm sisal fiber (18% wt) + Graphite (6% wt)
S4	Polyester (61% wt) + 60 mm sisal fiber (35% wt) + Graphite (4% wt)
S5	Polyester (69% wt) + 60 mm sisal fiber (25% wt) + Graphite (6% wt)
S6	Polyester (80% wt) + 60 mm sisal fiber (18% wt) + Graphite (2% wt)
S7	Polyester (59% wt) + 80 mm sisal fiber (35% wt) + Graphite (6% wt)
S8	Polyester (73% wt) + 80 mm sisal fiber (25% wt) + Graphite (2% wt)
S9	Polyester (78% wt) + 80 mm sisal fiber (18% wt) + Graphite (4% wt)

Taguchi Method

The need of optimization is to obtain the best result. By altering the input parameters, the optimization process seeks for improved output so that the performance of a system can be enhanced. Taguchi method is produced by Dr. Genichi Taguchi in 1950 and is a combination of mathematical and statistical technique. It is an optimization technique whose main focus is only on producing high quality product at relatively low cost and less time in compare to conventional full factorial technique. The two major tools used in Taguchi method are signal-to-noise(*S/N*) ratio and orthogonal arrays [10-11]. Experiments based on Taguchi methods were performed as per the specifically designed orthogonal array in which control factors or process parameters were taken as input parameters. The experimental result analysis uses *S/N* ratio to aid in the determination of the best process or product design.

Table 3: Levels of Variables used in the experiment

Control factors	Levels			Units
	I	II	III	
Fiber Length (A)	40	60	20	mm
Fiber Loading (B)	35	25	15	wt %
Filler Volume (C)	2	4	6	wt %
Normal Load (sliding wear) (D)	30	50	70	N
Normal Load (abrasive wear) (D)	10	15	20	N
Impact Angle (erosive wear) (D)	30	45	60	Degree

Table 3 shows Taguchi (L9) orthogonal array, which is based on different wear test which is performed under room temperature. In this table each column shows test parameter and each row shows parameter levels. According to conventional or full factorial experiment with four parameters with three levels requires 43=64 runs which reduces to only 9 runs, by using Taguchi orthogonal array. The results (or outputs) obtained from different wear test were then converted into S/N ration. The *S/N* ratios serve as the objective functions for optimization, and help in analysis of data and optimum results prediction.

Table 4: Experimental design using L_9 orthogonal array

Sample No	Fiber Length (in mm) (A)	Fiber Loading (in wt %) (B)	Filler Volume (in wt %) (C)	Normal Load(in N) (for adhesive wear)(D)	Normal Load(in N)(for abrasive wear) (D)	Impact Angle (in Degree) (for erosive wear) (D)
S1	40	35	2	30	10	30
S2	40	25	4	50	15	45
S3	40	18	6	70	20	60
S4	60	35	2	70	20	60
S5	60	25	4	30	10	30
S6	60	18	6	50	15	45
S7	20	35	2	50	15	45
S8	20	25	4	70	20	60
S9	20	18	6	30	10	30

There are three types of quality characteristics which can be used in the analysis of S/N ratio. This are-

- **Smaller the better**
- **Larger the better**
- **Nominal the best**

These three characteristics can be calculated by using equations which shown below: -
Smaller the better: $S/N = -10 \log10/n(\sum y^2)$ …….1
Larger the better: $S/N = 10 \log10(\bar{Y}/S^2)$ ……….2
Nominal the better: $S/N = -10 \log10/n(\sum 1/y^2)$….3
Where, n is no. of observation, $\bar{Y}$ is mean, y indicates observed data and S denotes variance. S/N ratio for wear comes under **"smaller the better"** characteristics which can be calculated by using equation 1.

Wear Test
Three wear test were performed on produced composite samples. These are:-

- Adhesive Wear Test (Pin on disc test)
- Abrasive Wear Test (Two Body)
- Erosive Wear Test (Air jet)

1) Adhesive Wear Test (Pin on disc test)

Adhesive wear test is performed on Pin-on-disc type tribometer as per **ASTM G 99** test standard. Setup for this test is capable of creating sliding wear environment so that wear properties of prepared composite can be analyzed. This type of tribometer mainly consists of stationary pin or ball which rubbed against rotating steel disc or counter disc. This rotating steel disc is made up of EN31 steel hardened to 60 HRC of 120 mm diameter and 8 mm thick. The sample or pin is dead weighted loaded through a string to which pan assembly is attached. This test is conducted under variable parameters such as sliding velocity of disc, load applied, sliding is tance and wear track along with variable test conditions such as discorpin temperature and in lubricated or dry conditions. The operation of pin-on-disc tribometer is fully auto controlled by user-friendly software (WINDUCOM) which running on operating system windows2007.

Figure 2: Pin on disc tribometer

Table 5: Pin on disc type tribometer parameters

Factors	Parameters
Sliding Velocity	3 m/sec
Sliding Distance	1000 m
Normal Load	30, 50 and 70 N
Wear Track	100 cm
Disc Rotation Speed	200 rpm
Frictional Force	200 N
Timer	333 sec
Condition	Dry

For specimen of Adhesive wear
Length = 10mm, Width = 7mm, Thickness = 10 mm

2) Abrasive Wear Test (Two body)

The two body abrasive wear test is performed on **Two Body Abrasion Tester** as per **ASTM D 6037** test standard. In two body abrasion testing apparatus the sample which is used for testing is allowed to slide over rotating circular wheel. An Abrasive paper (of grade 150) is wrapped over periphery of circular wheel. Then due to relative motion between rotating circular wheel and testing sample causes removal of material.

Figure 3: Two body abrasion wear tester and samples after abrasion wear test

Table 6 Two body Abrasion Test Parameters

Parameters	Values
Load	10,15,20 N
Speed	50 m/sec
No of sliding cycle	400
Abrasive Grade	150

For Specimen of Abrasive wear
Length = 30mm, Width = 30mm, and thickness = 10mm.

3) Erosive Wear Test (Airjet)

Erosive wear test is performed on **Air Jet Erosive Tester** as per **ASTM G 76** test standards. Setup of this test is capable of creating erosive wear environment so that wear properties of prepared composites can be analyzed. The apparatus of air jet erosion wear tester are- Sample holders for different angles of impingement, Erodent, Nozzle, Hopper (to collect erodent), Cradle and Compressor (to maintain air jet pressure).

Figure 4: Air jet erosion wear tester samples fitted in different angle of impingement

Table 7 Air jet erosive wear test parameters

Parameters	Values
Impingement Angle	30^0,60^0,90^0
Velocity	30 – 100 m/sec
Air Jet Pressure	0.76 bar
Erodent Feed Rate	10 g/min
Erodent Size	50 µm
Erodent Name	Alumina Al_2O_3, Silica
Temperature	Room Temperature (25-28^{0}C)
Time duration of test	10 min

For specimen of Erosive wear
Length = 50mm, Width = 50mm and Thickness = 10 mm

III. RESULT AND DISCUSSION

1) Adhesive wear test (pin on disc test)

Experimental results for adhesive wear carried out according to Taguchi experimental design on sisal fiber reinforced polyester composite is shown in table 8. This table provides experimental wear along with S/N ratio.

Table 8: Experimental results for Adhesive wear

Sample No	Fiber Length (in mm) (A)	Fiber Loading (in wt %) (B)	Filler Volume (in wt %) (C)	Normal Load(in N)(D)	Erosive Wear (in gram)	S/N Ratio (in dB)
S1	40	35	2	30	0.0347	29.193
S2	40	25	4	50	0.0323	29.816
S3	40	18	6	70	0.0283	30.964
S4	60	35	2	70	0.0370	28.624
S5	60	25	4	30	0.0269	31.389
S6	60	18	6	50	0.0342	29.319
S7	20	35	2	50	0.0347	29.181
S8	20	25	4	70	0.0382	28.359
S9	20	18	6	30	0.0361	28.850

Analysis of effects of control factors (fibre length, weight % of sisal fibre, weight % of graphite filler and normal load) are obtained from response table of mean S/N ratio which is shown in table 9.

Table 9: Response table for Adhesive wear

Response Table for Signal To Noise Ratio Smaller is Better				
Level	Fibre Length (in mm)	Fibre Loading (in wt %)	Filler Volume (in wt %)	Normal load (in N)
1	0.03635	0.03287	0.03570	0.03258
2	0.03177	0.03248	0.03515	0.03375
3	0.03273	0.03550	0.03000	0.03452
Delta	0.00458	0.00302	0.00570	0.00193
Rank	2	3	1	4

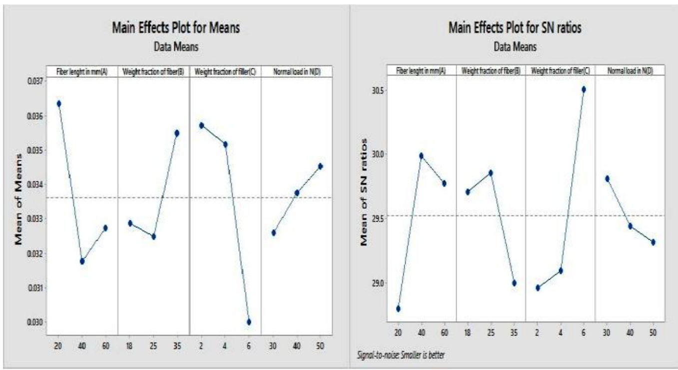

Figure 5: Main effects plots for means and S/N ratios for Adhesive wear

Discussion: -

- Results of adhesive (or sliding) wear test of all the samples is show n in fig.5.
- It is clearly seen from the graph that **A2B2C3D1** shows higher S/N ratio i.e. at 40mm fibre length, 25 wt% fibre loading, 6 wt% filler volume and 10 N normal load value of S/N ratio is higher and we know that larger value of S/N ratio

gives better quality. Therefore optimal combination of design parameters can be obtained as**A2B2C3D1**.

2) Abrasive wear test (Two body)

Experimental results for two body abrasive wear carried out according to Taguchi experimental design on sisal fiber reinforced polyester composite is shown in table 10. This table provides experimental wear along with S/N ratio.

Table 10 Experimental results for two body abrasive wear

Sample No	Fiber Length (in mm) (A)	Fiber Loading (in wt %) (B)	Filler Volume (in wt %) (C)	Normal Load (in N)(D)	Erosive Wear (in gram)	S/N Ratio (in dB)
S1	40	35	2	10	0.0694	23.173
S2	40	25	4	15	0.0646	23.795
S3	40	18	6	20	0.0566	24.944
S4	60	35	2	20	0.0741	22.604
S5	60	25	4	10	0.0539	25.368
S6	60	18	6	15	0.0684	23.299
S7	20	35	2	15	0.0695	23.160
S8	20	25	4	20	0.0764	22.338
S9	20	18	6	10	0.0722	22.829

Analysis of effects of control factors (fibre length, weight % of sisal fibre, weight % of graphite filler and normal load) are obtained from response table of mean S/N ratio which is shown in table 11.

Table 11 Response table for Abrasive wear

Response Table for Signal To Noise Ratio Smaller is Better				
Level	Fibre Length (in mm)	Fibre Loading (in wt %)	Filler Volume (in wt %)	Normal load (in N)
1	0.07270	0.06573	0.07140	0.06517
2	0.06353	0.06497	0.07030	0.06750
3	0.06547	0.07100	0.06000	0.06903
Delta	0.00917	0.00603	0.01140	0.00387
Rank	2	3	1	4

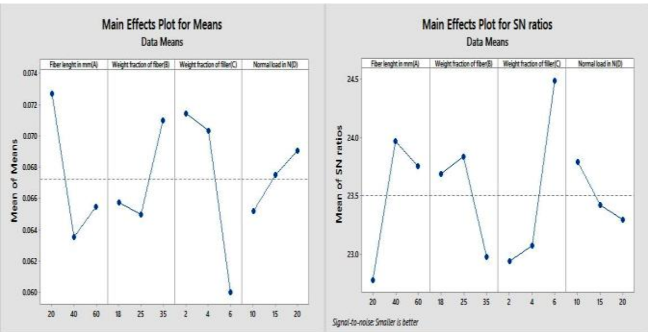

Figure 6: Main effects plots for means and S/N ratios for Abrasive wear

Discussion: -

- Results of two body abrasive wear test of all the samples is shown in fig.6
- It is clearly seen from the graph that **A2B2C3D1** shows higher S/N ratio i.e. at 40mm fibre length, 25 wt% fibre loading, 6 wt% filler volume and 30 N normal load value of S/N ratio is higher and we know that larger value of S/N ratio gives better quality. Therefore optimal combination of design parameters can be obtained as**A2B2C3D1.**

3) Erosive wear test

Experimental results for erosive wear carried out according to Taguchi experimental design on sisal fiber reinforced polyester composite is shown in table 12. This table provides experimental wear along with S/N ratio.

Table 12: Experimental results for erosive wear

Sample No	Fiber Length (in mm) (A)	Fiber Loading (in wt %) (B)	Filler Volume (in wt %) (C)	Impact Angle (in Degree) (D)	Erosive Wear (in gram)	S/N Ratio (in dB)
S1	40	35	2	30	0.0016	55.918
S2	40	25	4	45	0.0013	57.721
S3	40	18	6	60	0.0029	50.752
S4	60	35	2	60	0.0026	51.701
S5	60	25	4	30	0.0020	53.979
S6	60	18	6	45	0.0028	51.057
S7	20	35	2	45	0.0028	51.057
S8	20	25	4	60	0.0030	50.458
S9	20	18	6	30	0.0019	54.425

Analysis of effects of control factors (fibre length, weight % of sisal fibre, weight % of graphite filler and impact angle) are obtained from response table of mean S/N ratio which is shown in table 13.

Table 13: Response table for Erosive wear

Response Table for Signal To Noise Ratio				
Smaller is Better				
Level	Fibre Length (in mm)	Fibre Loading (in wt %)	Filler Volume (in wt %)	Impact Angle (in degree)
1	0.002567	0.002533	0.002467	0.001833
2	0.001933	0.002100	0.001933	0.002300
3	0.002467	0.002333	0.002567	0.002833
Delta	0.000633	0.000433	0.000633	0.001000
Rank	4	3	2	1

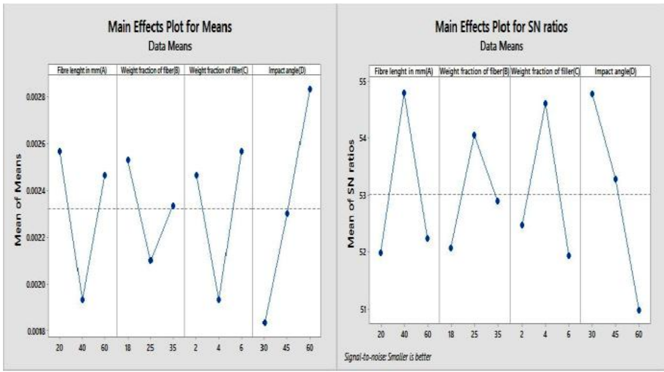

Figure 7: Main effects plots for means and S/N ratios for Abrasive wear

Discussion: -

- Results of erosive wear test of all the samples is shown in graph 4.1.1 and4.1.2
- It is clearly seen from the graph that **A2B2C2D1** shows higher S/N ratio i.e. at 40mm fiber length, 25 wt% fiber loading, 4 wt% filler volume and 30^0 impingement angle value of S/N ratiois higher and we know that larger value of S/N ratio gives better quality. Therefore optimal combination of design parameters can be obtained as**A2B2C2D1.**

IV. CONCLUSION

With the aim of development of Sisal based composites and Characterization of Tribological Properties of Sisal Fiber Reinforced Polymer Composites have been studied. The major Tribological properties like Adhesive wear (pin on disc type), Abrasive wear (two body) and Erosive wear (airjet) were reported. Also optimization of two body abrasive, erosive, and adhesive wear test parameter sdone with the help of Taguchi analysis. It can be concluded from S/N ratio that optimal combination of design parameters can be obtained at **A2B2C2D1** (for erosive wear), **A2B2C3D1** (for two body abrasive wear) and **A2B2C3D1** (for sliding or adhesive wear) for prepared composite.

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