STATISTICAL FEATURES OF EPOXY RESIN BASED HYBRID COMPOSITES REINFORCED WITH JUTE, BANANA AND FLAX NATURAL FIBERS

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ABSTRACT

This paper treats the wear behavior of epoxy resin composites reinforced with jute, banana and flax natural fibers. The test specimens are prepared and tested as per ASTM standard. The experiments are conducted by using a pin on disc machine. An empirical relation is used to estimate the wear using a statistical regression analysis, Yate's algorithm and a variance analysis (ANOVA) for the hybrid composites. The results indicate that the highest wear is observed in case of 20 % fiber volume fraction and 500 rpm, while the lowest one is found at 30 % volume fraction and 300 rpm. The composites fracture surface shows ductile tear ridges and cracked fiber particles indicative of both ductile and brittle fractures.

Keywords: banana fibres, uniaxial glass fibres, jute, flax fibres, epoxy resin, statistical features.

INTRODUCTION

Presently the world is facing a tough time because of environment deterioration due to large amounts of pollution and increasing levels of CO_2 emissions. In this aspect natural fibre composites do play a suitable role. It is so because the natural fibres are eco-friendly, renewable, possess good strength and stiffness. Besides, they have good sound absorption capacity and excellent thermal properties.

Benyahia et al. [1] reported that the removal of lignin and hemi cellulose through an alkaline treatment resulted in a rougher surface, which in turn favored mechanical interlocking and bonding reaction due to exposure of the matrix hydroxyl groups. This in turn increased the mechanical adhesion. Vivek et al. [2] found that the composite hardness increased with the the fiber loading increase. The higher volume fraction resulted in a higher composite modulus. The higher volume fraction provided also an efficient fiber impact transfer on the composite sample. Narendiranath Babu et al. [3] suggested that an addition of jute increased the wear resistance of the composite sample and resulted in a decrease of the values of the coefficient of friction by 3.5 % and those of the specific wear rate by 65 %. Compression moulding was used for the manufacture of the jute propylene composites. It was also concluded that the effect of the reinforcements on the value of the coefficient of friction was very little. M Jawaid et al. [4] studied the chemical resistance of a jute fiber reinforced composite and the void formation effect on the mechanical properties of the composite. It was found that the adhesion and mechanical properties of the hybrid fibers were improved. It was also concluded that the jute fabric layer on the outer surface provided maximum of the tensile strength while the oil palm core absorbed maximum of the stresses. Hence, jute overlapping the EFB fibres acted better than EFB overlapping jute.

H. Brodowsky et al. [5] found that the presence of a coupling resin agent in the composite stimulated the adhesion in the interphase of the fiber and the matrix through a chemical bonding. The interphase even though occupying a small volume of the composite greatly affects the mechanical properties and which is why the chemical bonding in this region brought about great improvement. R.A.Braga et al. [6] studied experimentally the effect of hybrid reinforcement involving jute hybridization with glass fiber. The tensile strength of the composites increased, but there was no observable change in the flexural strength or the impact energy and the composites containing more jute fibers absorbed more water than those of a high percentage of glass fibers. M Ramesh et al. [7] observed that treated banana fibers had a higher degree of adhesion and better bonding ability with hydrophobic resins. Besides, the weight loss percentage was lower when compared to that of untreated fibers. It was found that the composition referring to 60 % of epoxy and 40 % of banana fibers showed the highest load bearing capacity. The SEM analysis applied indicated that the chemically treated banana provided good adhesion, better bonding and a high crystalline index.

Alavudeen et al. [8] concluded that the orientation of the banana fibers affected also their properties. Maximum increase in mechanical properties was observed in case of plain woven banana fabrics when compared to that in presence of random orientated fibers. It was also observed that the strength of kenaf fiber reinforced composites was higher when compared to that of the banana fiber hybrid composite. The plain woven fiber composites showed better properties than those of the twill woven one irrespective of the fiber used. The tensile strength of the composite was higher when the fibers were oriented in a longitudinal direction. K Senthil Kumar et al. [9] studied the vibrational behavior of a banana fiber reinforced composite, and observed that the skin core type oriented treated fibers exhibited better properties when compared to those of the skin eccentric type.

The friction coefficient and the wear rate of a composite filled with a natural fabric decreased remarkably with load increase. When TiO_2, $BaSO_4$, SiC and graphite were added simultaneously, the friction coefficient and the wear rate of the composites decreased [10-18]. An adhesive wear took place with the applied load increase. It was generally less dangerous for the polymer composite sliding surface. The fillers used to transfer films on the counterpart surface could provide a better quality at a higher load compared to that obtained at a lower load. The plowing and scuffing would be excluded, while the tribological behavior could be improved in case of formation of higher quality transfer films [19-24].

The major objectives of this research work refer to:

- the study of the effect of various factors on the wear rate like the volume fraction of the reinforcement, the load, the speed, the sliding distance and the determination of the dominating one;
- the comparison of the tribological properties of hybrid composites containing three natural fibers.

EXPERIMENTAL

Natural fibers such as jute, banana and flax along with synthetic uniaxial glass fibers of 360 g m^{-2} and a diameter of 5 μm - 10 μm were employed. A viscosity epoxy resin (LY556) acting as a matrix system and a room temperature cured polyamine hardener (HY951), both supplied by Shakti glass fibers, were used.

Investigation Method

The investigation design included:

Step 1: Identification of the major factors affecting the wear behavior of the hybrid fiber matrix composites.

Step 2: Preparation of a reinforced hybrid composite material containing natural and glass fibers.

Step 3: Calculation of the upper and lower limits of the factors identified.

Step 4: Improvement of the design matrix developed.

Step 5: Performance of experiments following the design matrix.

Step 6: Formulation of a mathematical model.

Step 7: Determination of the coefficients of the factors.

Step 8: Examination of the adequacy of the developed model by using ANOVA method.

Step 9: Analysis of the effect of the volume fraction, the applied load, the rotational speed and the counterface hardness on the wear behavior in case of a dry sliding fiber-to-metal contact.

Material Specifications

Table 1 shows the sample numbers and the corresponding specifications. Table 2 lists the properties of the different natural fibers, while Table 3 presents the properties of Epoxy 556 cured with Araldite LY 556.

Sample preparation

The natural fibers were initially treated with 10 % NaOH solution aiming to remove their lignin and hemicellulose layers. Then they were dried in the sun, subsequently washed with soft water and left to dry for a day. After that the fibers were compressed under a uniform load aiming to obtain a uniform thickness. Then epoxy and a hardener were mixed in a ratio of 10:1 and stirred thoroughly to ensure the mixture homogenization. After 10 min a layer of the mixture was inserted in the mould. Then a layer of releasing agent was applied so that the sample could be easily removed from the mould. Then alternate layers of glass and natural fibers were applied in between the epoxy layers reaching a thickness of 4 mm. Then a uniform load was applied on the sample so that the epoxy layer impregnated the fiber layers and a compact bonding was achieved. Then the sample was left to cure for 24 h under normal ambient conditions. The samples used for testing the tribological properties of the natural composites were prepared in a similar way. Circular hot water pipes were used for the moulding purpose.

Experimental Procedure

1. A pin-on-disc test setup was used for slide wear experiments.
2. The surface of the sample (5 mm x 5 mm) glued to a pin with 6 mm diameter and 22 mm length was brought in a contact with a disc of hardness of 60 HRC.
3. The counter surface disc made of En 31 steel was of 165 mm diameter, 8 mm thickness and surface roughness (Ra) of 1.6 μm.
4. The test was conducted on 115 mm diameter track for specified test duration, load and velocity.
5. Prior to testing, the test samples were rubbed against a 600-grade SiC paper.
6. The pin assembly was initially weighed using a digital electronic balance (0.1 mg accuracy).
7. The test was carried out by applying a normal load (ranging from 30 N to 70 N) and run for a constant sliding distance (5000 km) at different sliding velocities (3 m/s, 4 m/s and 5 m/s).
8. At the end of the test, the pin assembly was again weighed using the same balance.
9. The difference between the initial and the final weight was treated as a measure of the slide wear loss. A minimum of three trials was conducted to ensure repeatability of the test data.
10. The friction force at the sliding interface of the specimen was measured at an interval of 5 min using a frictional load cell.

Mathematical Modeling

Identification of predominant factors

The wear properties are affected by many factors, such as the temperature generated during bearing running, the chemical composition of the material, the volume percentage, the size reinforcement, etc.

The literature review shows that the predominant factors which influence the wear of the glass epoxy composite refer to the volume percentage of the reinforcement, the applied load, and the sliding distance. Table 2 lists the major factors treated in the test. A detailed analysis is carried out to fix the lower and the upper limits of the factors values ranges. They are fixed based on the analysis carried out.

Developing the mathematical model

Designating the composite material wear by W, the response function can be represented as W = f{A,B,C} where A, B and C are the three factors mentioned above. The high order interactions are practically insignificant

Table 1. Sample numbers and specifications.

S No.	Sample Number	Specifications
1	Jute20	10 % Jute, 10 % uniaxial glass fibers, 80 % Epoxy
2	Jute30	15 % Jute, 15 % uniaxial glass fibers, 70 % Epoxy
3	Flax20	10 % Flax, 10 % uniaxial glass fibers, 80 % Epoxy
4	Flax30	15 % Flax,15 % uniaxial glass fibers, 70 % Epoxy
5	Banana20	10 % Banana, 10 % uniaxial glass fibers, 80 % Epoxy
6	Banana30	15 % Banana, 15 % uniaxial glass fibers, 70 % Epoxy

Table 2. Properties of the natural fibers used.

Type	Density (g/cm^3)	Elongation (%)	Tensile Strength (MPa)	Young's Modulus (GPa)	Specific Gravity	Specific Modulus (GPa)
Jute	1.3-1.5	1.4-2.1	385-850	9-31	1.3-1.5	6.9-20.7
Banana	0.5-1.5	2.4-3.5	711-789	4-32.7	1.1-1.2	3.6-27.3
Flax	1.3-1.5	1.1-3.3	340-1600	25-81	1.5	16.7-54

in engineering problems and hence they are not measured. The variance analysis (ANOVA) is used for finding the significance factors. The Yate's algorithm is applied to find the sum of squares for main and interaction effects. Table 4 shows the Yates algorithm, where $\beta_1, \beta_2, \ldots.\beta_i$ are calculated using the following equation:

$$\beta i = \sum \frac{XY}{N}$$

where i varies from 1 to n, Xi is the corresponding coded value of the process parameters considered in the experiment, Yi is the corresponding response output obtained from the experimental results, while N is the total number of combinations of the treatment considered.

Designing the Mathematical Model

The mathematical expression of the wear rate of the composites (W) is expressed as W = f (A,B,C,D) where A,B and C are the various parameters enlisted above. Excluding the higher order multiples, which are not taken into consideration in this type of solutions, the mathematical model is described as

$$Wear = \alpha_0 + \alpha_1(A) + \alpha_2(B) + \alpha_3(C) + \alpha_4(D) + \alpha_5(AB) + \alpha_6(AC) + \alpha_7(AD) + \alpha_8(BC) + \alpha_9(BD) + \alpha_{10}(CD)$$

where α_0 is the average output value, while $\alpha_{1,} \alpha_{2,} \alpha_3$ are the coefficients that depend on the factors and the interaction details.

Creating the Design Matrix

The factors selected are very closely spaced in view of the two level factorial design of Yate's algorithm accepted. The detailed symbols, levels and their corresponding values are listed in Table 1. In order to make the calculations easy and smooth the upper and lower levels are taken as +1 and -1, respectively. The values of the parameters at any intermediate level can be found out using the formula:

$$Y=(X- [X_{max}+X_{min}]/2)/(X_{max}-X_{min})/2$$

where X_{max} is the maximum level of the parameter, X_{min} is the minimum level of the parameter, while Y is the required value of the parameter within the range.

RESULTS AND DISCUSSION

Yate's algorithm is applied to investigate the composites wear and to identify the major factors involved. There are several factors which can be taken into account when composite tribological properties are considered, i.e. the volume fraction, the morphology of the reinforcement, the pressure, the speed, the sliding distance variation, the hardness, the lubrication, etc. The wear test performed is that of a dry friction wear test. The main factors taken into this design modeling refer to (i) the volume fraction of the reinforcement (A); (ii) the rotational speed (B); (iii) the hardness (C); (iv) the fiber type (D). A detailed analysis is carried out to fix the upper and lower limits of the factors. The levels are selected following a proper scrutiny. Their values are given in Table 7.

Table 3. Properties of Epoxy 556 cured with Araldite LY 556.

S No.	Material Properties	Values
1	Young's Modulus	3200 MPa
2	Poisson's Ratio	0.35
3	Bulk Modulus	3665 MPa
4	Shear Modulus	1852 MPa
5	Tensile Ultimate Strength	88 Pa

Fixing the test limits of the design model

The random allocation of the samples for this test model is based on a trial and error approach aimed at showing a steady and constant wear rate. So a random allocation of 16 test samples is provided. A correlation between the experimentally observed results and those obtained by modeling is attempted to justify the scientific analysis of the wear test. The set of the values chosen is pretty close providing a magnified picture of the analysis which is intensive in its approach. Table 8 illustrates the design matrix and the corresponding output response.

The substantial factors are determined on the ground of the variance analysis (ANOVA). The sum of the squares is calculated for both the main and correlated factors applying the Yate's algorithm. Table 9 illustrates the wear results obtained.

The k columns (1), (2), . . . (k) are obtained by summation and subtraction of the appropriate pairs of numbers in case of application of the Yate's algorithm for a 2k factorial design. This is done in case of working with individual observations or the observations averages. The first divisor is 2k, while the remaining divisors are 2k1. The notation, the units and their levels are given in Table 4. Table 6 illustrates the Yates algorithm test results, while Table 7 presents obtained by ANOVA. Table 8 summarizes the main and the two factor interactions. In fact two different levels response tables are used to simplify the calculations required for the experimental data analysis. The effect of a factor on a response variable is outlined in the response tables as a change of the response, when the factor goes from its lower to its higher level. Table 8 shows that if the effect of a factor is greater than zero, the average response is higher for the higher level of the factor than for its lower one. In case the estimated effective value is less than zero or negative, the average response is higher at the lower level of the factor than that at the higher level. If the effect of a factor is very small, it is attributed to a random variation but not to a 'real' factor effect. This shows that the experimental values are well correlated with the predicted one.

The Yate's algorithm applied is formulated working with individual observations. k columns are used and the observations are generated by adding or subtracting the required pair of numbers. The ANOVA results are presented in Table 7. There the prominent factors and their interaction factors are listed in column 1, the sum of squares from the previous table are included in column 2, the values of the degree of freedom are listed in column 3, the values of the mean square obtained after dividing the sum of the squares by the degree of freedom are presented in column 4. The most important column in the table is the last one showing the F-ratio (Fischer F-Test 0) value which provides an insight of the most predominating factor in the Wear test. The values of $\alpha_{1,}$ $\alpha_{2.....}$ α_i are calculated using the expression:

$$\alpha_{i} = \Sigma(X_iY_i)/N$$

where i varies from 1 to n, X_i is the corresponding coded value of the factor considered in the experiment, Y_i is the corresponding output obtained in the experiment (in this case it's the total wear), while N is the total number of events considered or the total number of sample observations.

The effect of the different parameters is analyzed by using the standardized Pareto chart. Fig. 1 shows Pareto chart illustrating the standardized effects. It shows both the magnitude and the importance of the effect considered displaying the absolute value of the effects on the ground of a reference line. Any effect that extends the latter is potentially important. Higher order

Table 4. Major factors and their levels.

Sl No.	Factor	Notation	Unit	Levels			
				Coded		Original	
				Low	High	Low	High
1	Volume Fraction	A	%	-1	+1	20	30
2	Rotational Speed	B	Rpm	-1	+1	300	500
3	Hardness	C	HRC	-1	+1	25	35
4	Type of fiber	D		-1	+1	1	3

interactions do not usually reveal any significant effect in technical problems solution and hence three and four factor interactions are not considered. The response table is presented for the main and two factor interactions at two different levels (Table 8). Response tables are used to simplify the calculations required for experimental data analysis. There the effect of a factor on a response variable is expressed through the change in the response when the factor goes from its lower level to its higher one. In case the effect of a factor is greater than zero, the average response is higher for the higher level than that for the lower one. If the estimated effective value is zero or negative, it indicates that the average response is higher at the lower level. In case the effect of a factor is very small, then a random variation rather than a 'real' factor effect is accepted [17, 18]. The analysis of the Pareto chart and the response table shows that C, A, B, D are the main factors which influence the wear of hybrid metal matrix composites. Fig. 1 illustrates the normal probability plot of the standardized effects. The effects that are negligible are normally distributed, with mean zero and a variance. It is also concluded that factors A, B, C, D are significant at 95 % confidence level. Fig. 2 shows residuals against the observed order of data and it illustrates the good correlation between the experimental values and the predicted one. The plot is useful when the latter may influence the results. This occurs when the data is collected in a time sequence or in some other sequence such as a geographic area. According to Fig. 2 the residuals are distributed properly. A certain correlation is also present. The plot does not reveal any obvious pattern and hence the fitted model is adequate. Fig. 3 shows residuals against the predicted values and Fig. 4 shows predicted versus actual values.

After conducting a number of experiments, the following observations are made: (i) the wear is almost equal to the unreinforced composite when the reinforcement volume is less than 10 %; (ii) more abrasion is created in case the volume composition is greater than 20 %.

Common observations:

1. Maximum wear is observed in case of 20 % fiber volume fraction and 500 rpm, while it is at its minimum value at 300 rpm and 30 % volume fraction.

2. The coefficient of friction of both kinds of compositions considered is better than that of G-E (glass fiber + epoxy) sample only.

3. A deviation of only 2 % to 5 % is observed between the coefficient of friction values for the jute, banana and flax samples.

4. Lubricated conditions are found to provide reasonably better results under dry conditions in all cases. Thus these are the best conditions studied.

5. The working preference in respect to the bearing material would be 20 % composition > 10 % composi-

Table 5. Design matrix and the corresponding output response.

Sl No.	Coded Value				Original Value				Wear (μm)
	A	B	C	D	A	B	C	D	
1	-1	-1	-1	-1	20	300	25	1	240
2	+1	-1	-1	-1	30	300	25	1	185
3	-1	+1	-1	-1	20	500	25	1	300
4	+1	+1	-1	-1	30	500	25	1	200
5	-1	-1	+1	-1	20	300	35	1	210
6	+1	-1	+1	-1	30	300	35	1	120
7	-1	+1	+1	-1	20	500	35	1	285
8	+1	+1	+1	-1	30	500	35	1	190
9	-1	-1	-1	+1	20	300	25	3	290
10	+1	-1	-1	+1	30	300	25	3	225
11	-1	+1	-1	+1	20	500	25	3	380
12	+1	+1	-1	+1	30	500	25	3	330
13	-1	-1	+1	+1	20	300	35	3	275
14	+1	-1	+1	+1	30	300	35	3	205
15	-1	+1	+1	+1	20	500	35	3	356
16	+1	+1	+1	+1	30	500	35	3	307

Table 6. Yate's algorithm used for sum of squares calculation.

Sl No.	Wear (μm)	1	2	3	4	Symbol	Sum of Squares
1	240	425	925	1730	4098	I	1049600
2	185	500	805	2368	-574	A	20592.25
3	300	330	1225	-340	598	B	22350.25
4	200	475	1143	-234	-14	AB	12.25
5	210	515	-155	220	-202	C	2550.25
6	120	710	-185	378	-26	AC	42.25
7	285	480	-115	-50	58	BC	210.25
8	190	663	-119	36	46	ABC	132.25
9	290	-55	75	-120	638	D	25440.25
10	225	-100	145	-82	106	AD	702.25
11	380	-90	195	-30	158	BD	1560.25
12	330	-95	183	4	86	ABD	462.25
13	275	-65	-45	70	38	CD	90.25
14	205	-50	-5	-12	34	ACD	72.25
15	356	-70	15	40	-82	BCD	420.25
16	307	-49	21	6	-34	ABCD	72.25

tion > glass fiber with epoxy only in terms of the various loads work performance for specific time duration at a standard working velocity.

The regression coefficient of the Yate's algorithm application is to be calculated. The value of R^2 and that of adjusted R^2 are determined. The first one is found equal to 0.9779, while the second one amounts to 0.9448. This indicates that the model predicts correctly the wear rate of the composites. S/N ratio is additionally calculated aiming more precise and adequate analysis. Usually a value greater than 4 is preferred. That provided by the present model is equal to 5.49, which is a good result. Hence, the above model analysis can be used to predict the hybrid composites wear.

The effect of the parameters tested

The effect of the various parameters on the hybrid composite wear rate can be analyzed by: (i) Pareto chart; (ii) 3-D graphs.

Analysis by using Pareto Chart

The effect of the various factors on the total wear is analyzed using Pareto chart. Fig. 1 illustrates its application. It identifies the parameter affecting the wear and its intensity. The chart displays the absolute magnitude of any effect. A value greater than 4 within the 95 % confidence level is potentially crucial. The response table is formulated for the factors studied and their interactions (Table 5).

It presents the data in a form providing an easy implementation and interpretation. The effect of each factor is considered in the course of its lower to higher level shift. If the effect of any factor is greater than zero, its average response will be greater for the factor higher level when compared to that at its lower level. The opposite is valid when the effect of any factor is less than zero. The Pareto graph in Fig. 1 provides to conclude that factors A, B and D are very significant for the composites wear. From Fig. 2 it is evident that the positive and negative residuals are properly

Table 7. ANOVA test results.

Factors	Sum of Squares	Degree of Freedom	Mean Square	F-Ratio
A	20592.25	1	20592.25	88.81
B	22350.25	1	22350.25	96.39
C	2550.25	1	2550.25	11
D	25440.25	1	25440.25	109.72
AB	12.25	1	12.25	0.05
AC	42.25	1	42.25	0.182
AD	702.25	1	702.25	3.028
BC	210.25	1	210.25	0.906
BD	1560.25	1	1560.25	6.73
CD	90.25	1	90.25	0.389
Error	1159.25	5	231.85	

distributed which indicates a good correlation. From Fig. 3 it is observed that the graph does not follow a specified pattern and hence the design model is perfect. From Fig. 4 it is clearly seen that the vallues considered are closely correlated.

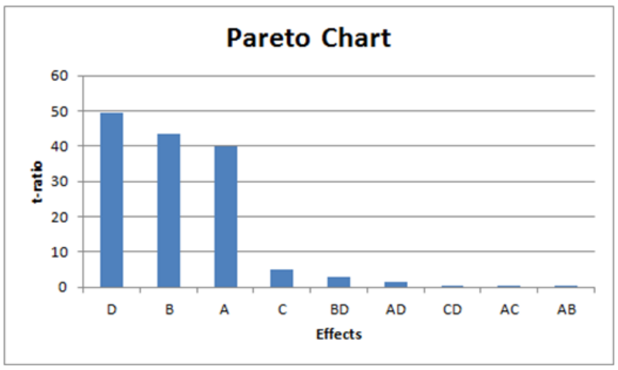

Fig. 1. Pareto chart illustrating the standardized effects.

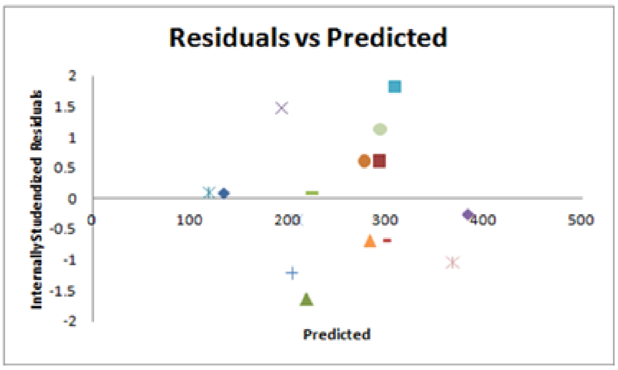

Fig. 3. Residuals against the predicted values.

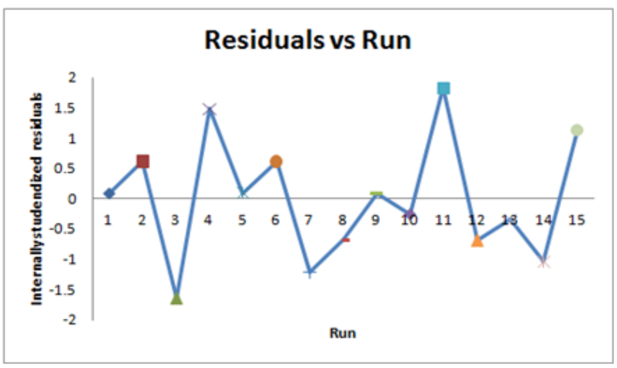

Fig. 2. Residuals against the observed order of data.

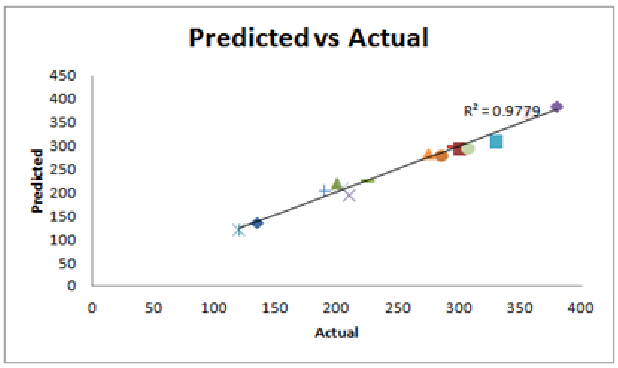

Fig. 4. Predicted versus actual values.

Table 8. Wear response table.

S No.	Wear (µm)	A		B		C		D		AB		AC		AD		BC		BD		CD	
		-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1
1	240	240		240		240		240			240		240		240		240		240		240
2	185		185	185		185		185		185		185		185			185		185		185
3	300	300			300	300		300		300			300		300	300		300			300
4	200		200		200	200		200			200	200		200		200		200			200
5	210	210		210			210	210			210	210			210	210			210	210	
6	120		120	120			120	120		120			120	120		120			120	120	
7	285	285			285		285	285		285		285			285		285	285		285	
8	190		190		190		190	190			190		190	190			190	190		190	
9	290	290		290		290			290		290		290	290			290	290		290	
10	225		225	225		225			225	225		225			225		225	225		225	
11	380	380			380	380			380	380			380	380		380			380	380	
12	330		330		330	330			330		330	330			330	330			330	330	
13	275	275		275			275		275		275	275		275		275		275			275
14	205		205	205			205		205	205			205		205	205		205			205
15	356	356			356		356		356	356		356		356			356		356		356
16	307		307		307		307		307		307		307		307		307		307		307
Avg	256.1	292	220	219	294	269	244	216	296	257	265	258	254	250	263	253	260	269	266	254	259
Effect		.92		75		.25		80		8		.4		13		7		.3		5	

Analysis using 3-D response graphs

Fig. 5 shows wear response as a function of the fiber type and the hardness value. Fig. 6 shows wear response as a function of the fiber type and the speed value. Fig. 7 shows wear response as a function of the hardness and speed values. Fig. 8 shows wear response as a function of the fiber type and the volume fraction values. Fig. 9 shows wear response as a function of the hardness and volume fraction values. Fig. 10 shows wear response as a function of the volume fraction and speed values.

The different response graph combinations available in case of the Yate's algorithm study of the composites tribological behavior are presented above. The surface plots comprise two planar axes presenting the parameters studied, while the resultant wear value is plotted on the third perpendicular axis. The highest point in the graph corresponds to the maximum wear value. Fig. 5 presents the plot for 300 rpm and 20 % volume fraction of varying fiber type and counter face hardness. It is seen that the maximum wear refers to a flax fiber reinforced composite and hardness of 25 HRC. In case of less hardness the composite easily wears away. At a rotational speed of 500 rpm the flax fiber reinforced composite shows maximum wear. This is clearly seen in Fig. 6. The wear is the maximum in case of 500 rpm and hardness of 25 HRC, whereas it is less for 300 rpm and hardness of 35 HRC as seen in Fig. 7. The wear is higher in case of 20 % fiber volume fraction and 500 rpm and minimum at 300 rpm and 30 % volume fraction. This is shown in Fig.10. It is evident that the graphs presented above predict clearly the wear value as a function of the parameters studied.

SEM analysis

Fig. 11 shows SEM image of 30 % Jute hybrid composite at a magnification of 500. Fig. 12 shows SEM image of 30 % Jute hybrid composite at a magnification of 1000. Fig. 13 shows SEM image of 30 % Flax hybrid composite at a magnification of 500. Fig. 14 shows SEM image of 30 % Flax hybrid composite

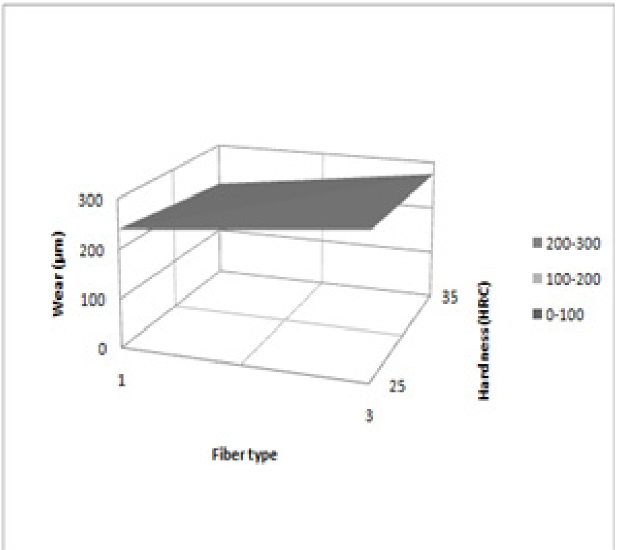

Fig. 5. Wear response as a function of the fiber type and the hardness value.

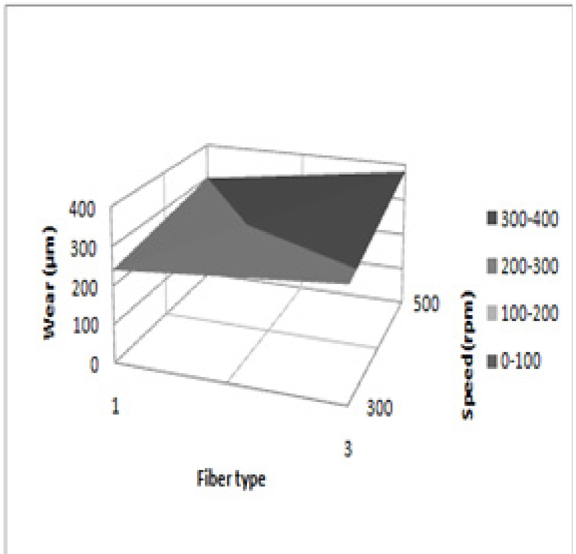

Fig. 6. Wear response as a function of the fiber type and the speed value.

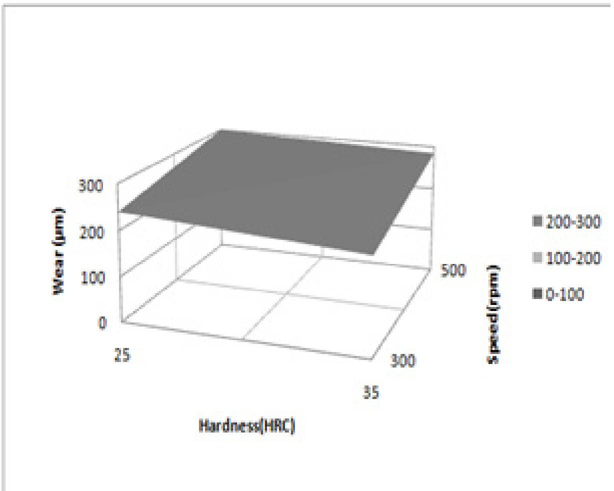

Fig. 7. Wear response as a function of the hardness and speed values.

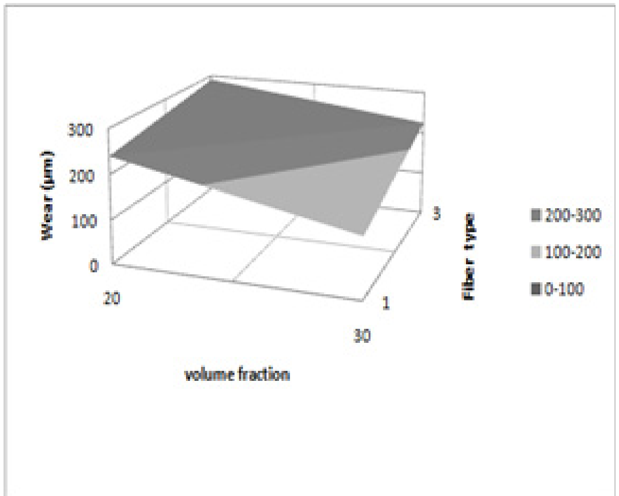

Fig. 8. Wear response as a function of the fiber type and the volume fraction values.

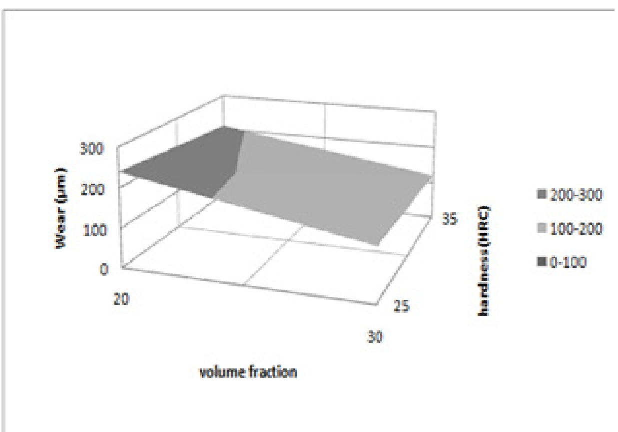

Fig. 9. Wear response as a function of the hardness and volume fraction values.

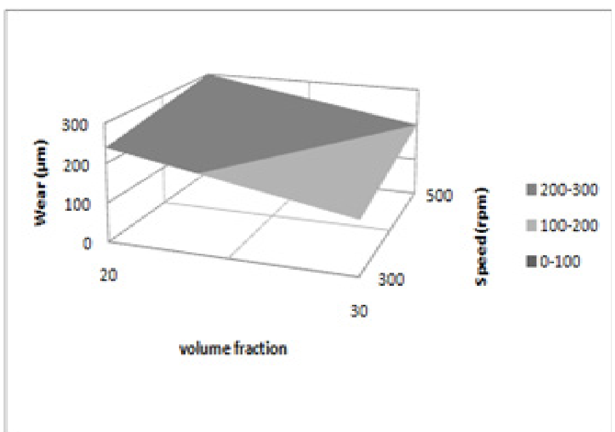

Fig. 10. Wear response as a function of the volume fraction and speed values.

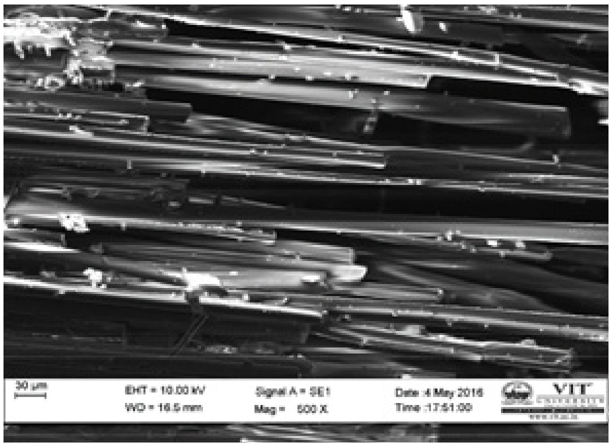

Fig. 11. SEM image of 30 % Jute hybrid composite at a magnification of 500.

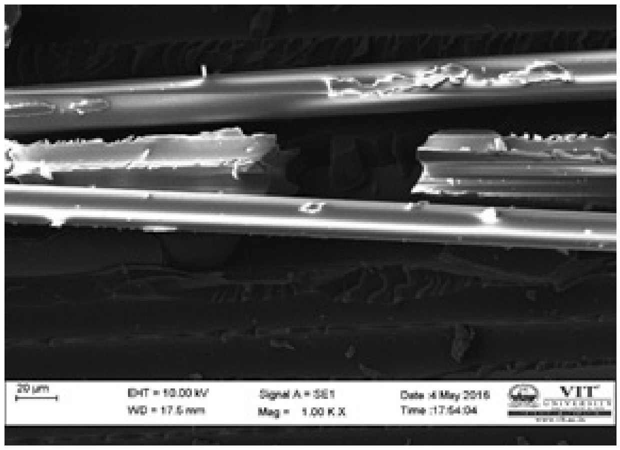

Fig. 12. SEM image of 30 % Jute hybrid composite at a magnification of 1000.

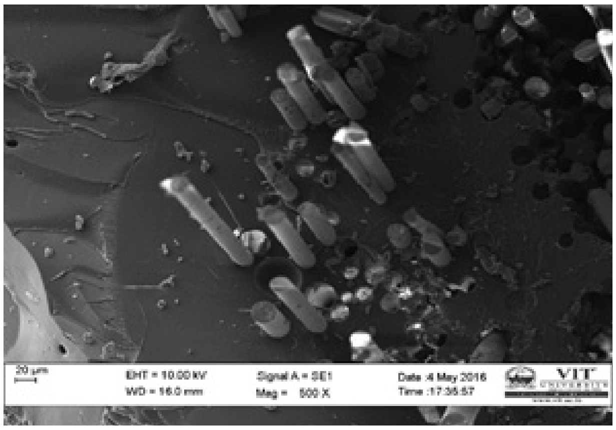

Fig. 13. SEM image of 30 % Flax hybrid composite at a magnification of 500.

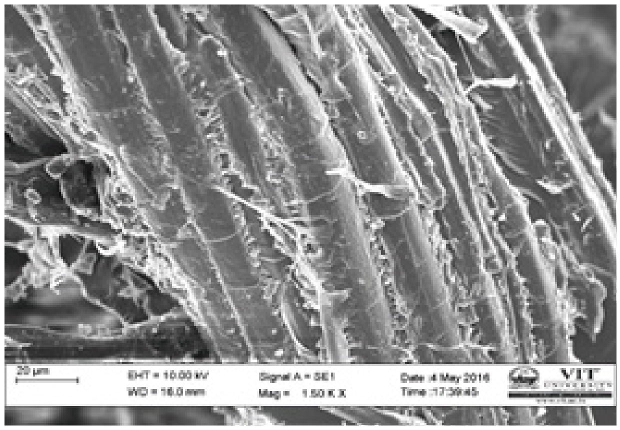

Fig. 14. SEM image of 30 % Flax hybrid composite at a magnification of 1500.

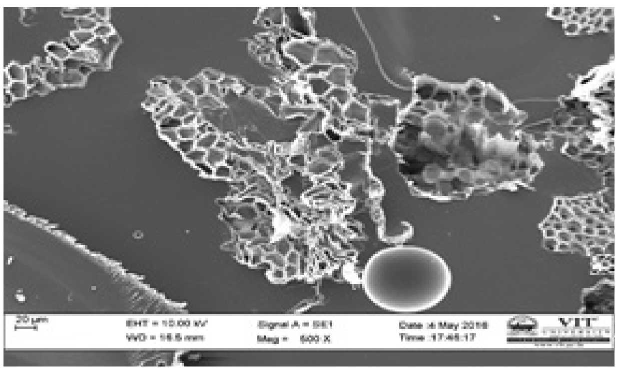

Fig. 15. SEM image of 30 % banana hybrid composite at a magnification of 500.

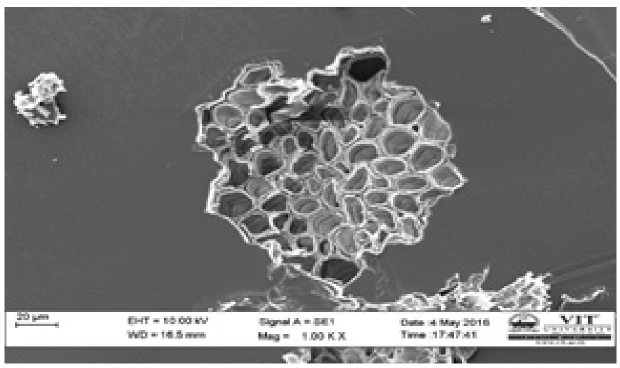

Fig. 16. SEM image of 30 % banana hybrid composite at a magnification of 1000.

at a magnification of 1500. Fig. 15 shows SEM image of 30 % banana hybrid composite at a magnification of 500. Fig. 16 shows SEM image of 30 % banana hybrid composite at a magnification of 1000.

SEM studies are performed to study the specimen failure mode. The region scanned is coated with a layer of silver prior to carrying the SEM analysis. The tested specimen image illustrates the pullout characteristics of the glass fiber and the breakage of the banana, jute, flax and uni-axial glass fibers. This is illustrated in Fig. 11 and Fig. 12. The glass and natural fibers absorb the majority of loads predominantly in the vertical direction.

The glass fiber alone shares some of the energy with the horizontally orientated fibers as it is in a woven form. The glass fiber displays high strength due to its superior properties. Fig.16 shows that the formation of the void between the fibers and the matrix affects greatly the mechanical properties of the laminates as banana has the lowest mechanical properties. A crack formation is initiated at a micro level in the course of the tensile test as depicted in Fig. 12. This refers to a laminate having three alternate layers of E-glass fibers. It is found that the crack is mainly due to inappropriate adhesion between the fibers and the matrix as well as to the poor load transferring capacity between the fibers. The SEM image of a natural fiber with three alternate layers of glass fibers subjected to a flexural test is shown in Fig. 14. The glass fiber in the hybrid combinations plays a vital role in flexural properties determination. The majority of the load is absorbed by these fibers. The remaining load following its failure is transferred to the banana and sisal fibers. The above studies show that the presence of voids, the improper adhesions between the fibers and the matrix, and the fiber pull out are the major causes for the laminate failure.

CONCLUSIONS

The paper focuses on the comparison of the tribological properties of three natural fibers hybridized with glass fibers. Experiments are performed to classify the samples properties. Wear tests are also performed. Optimization of the wear properties of the composites and SEM analysis are also carried out.

The following conclusions are drawn from the study reported.

The maximum wear in case of 300 rpm and 20 % volume fraction of a varying fiber type and counter face hardness is observed at point which corresponds to a flax fiber reinforced composite of hardness of 25 HRC. The composite easily wears away when the hardness is less.

The flax fiber reinforced composite shows a maximum wear at a high rotational speed of 500 rpm.

The wear is the maximum in case of 500 rpm and hardness of 25 HRC, whereas it is less for 300 rpm and hardness of 35 HRC.

The wear is higher for 20 % fiber volume fraction and 500 rpm and minimum at 300 rpm and 30 % volume fraction.

The Yate's algorithm suggests that the experimental data is well synchronized with the calculated values with a regression coefficient value of 0.9779 and "Adjusted R2" value of 0.9448. This shows that the model predicts correctly the composites wear rate. S/N ratio is additionally determined aiming more precise and adequate analysis. A value greater than 4 is generally preferred. The present model value is found equal to 5.49.

The 3D response graphs predict the wear value as a function of the factors studied.

• A marked improvement of the wear resistance is shown by the banana composite sample when compared to that of the flax sample.

• All the main factors such as hardness, speed and volume fraction have a significant effect on the wear behaviour of the hybrid composites. Among the three main factors, the volume fraction has a negative contribution, while the other two main factors have a positive impact, which implies that each individual factor increases the wear of the hybrid composites.

The wear test results suggest that the banana hybrid composite has the lowest specific wear rate. It can be considered for tribological applications in gears and bearing liners.

REFERENCES

1. A. Benyahia , A. Merrouche , M. Rokbib, Z. Kouadri, Study the effect of alkali treatment of natural fibers on the mechanical behavior of the composite unsaturated Polyester-fiber Alfa, 21ème Congrès Français de Mécanique, 2013.
2. Sandhyarani Biswas, Vivek Mishra, Physical and Mechanical Properties of Bi-directional Jute Fiber epoxy Composites, Procedia Engineering, 51, 2013, 561-566,
3. T. Narendiranath Babu, D. Rama Prabha, Wear Loss Behaviour of Reinforced Hybrid Composite Basalt Fiber With Titanium Oxide, Barium Sulphate And Silicon Carbide, Journal Of Chemical Technology And Metallurgy, 52, 1, 2017, 98-104.
4. Inderdeep Singh, Pradeep Kumar, Temesgen Berhanu Yallew, Sliding Wear Properties of Jute Fabric Reinforced Polypropylene Composites, Procedia Engineering, 97, 2014, 402-411.
5. A. Abu Bakar, H.P.S. Abdul Khalil, M. Jawaid, P. Noorunnisa Khanam, Chemical resistance, void content and tensile properties of oil palm/jute fibre

reinforced polymer hybrid composites, Materials and Design, 32, 2011, 1014-1019.

6. Edith Mäder, Hanna Brodowsky, Thi-Thu-Loan Doan, Jute fibre/epoxy composites: Surface properties and interfacial adhesion, Composites Science and Technology, 72, 2012, 1160-1166.
7. P.A.A. Magalhaes Jr, R.A. Braga, Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites, Materials Science and Engineering C, 56, 2015, 269-273.
8. C. Deepa, H. Eashwar, M. Ramesh, T.Sri Ananda Atreya, U.S. Aswin, Processing and Mechanical Property Evaluation of Banana Fiber Reinforced Polymer Composites, Procedia Enginnering, 97, 2014, 563-572.
9. A. Alavudeen, M. Thiruchitrambalam, N. Venkateshwaren, N. Rajini, S. Karthikeyan, Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: Effect of woven fabric and random orientation, Materials and Design, 66, 2015, 246-257.
10. I. Siva, J.T. Winowlin Jappes, K. Senthil Kumar, N. Rajini, S.C. Amico, Layering pattern effects on vibrational behavior of coconut sheath/banana fiber hybrid composites, Materials and Design, 90, 2016, 795-803.
11. A. Kumaravel, M. Kathirselvam and V.P. Arthanarieswaran, “Evaluation of mechanical properties of banana and sisal fiber reinforced epoxy composites: Influence of glass fiber hybridization”, Materials and Design, 64, 2014, 194-202.
12. Alain Dufresne, Foster A. Agblevor, Maha M. Ibrahim, Waleed K. El-Zawawy, Banana fibers and microfibrils as lignocellulosic reinforcements in polymer composites, Carbohydrate Polymers, 81, 2010, 811-819.
13. Hao Ma, Qian Li, Yan Li, The voids formation mechanisms and their effects on the mechanical properties of flax fiber reinforced epoxy composites, Composites: Part A, 72, 2015, 40-48.
14. Bin Yan, Bohumil Kasal, Haozhi Tan, Liang Huang, Libo Yan, Qi Xu, Reinforced Concrete Beams Strengthened with Externally Bonded Natural Flax FRP Plates, Composites:Part B, 2016.
15. Jiaxin Chen, Nawawi Chouw, Nonlinear flexural behaviour of flax FRP double tube confined coconut fibre reinforced concrete, Materials and Design, 93, 2016, 247-254.
16. N.Chand, U.K. Dwivedi, Effect of coupling agent on abrasive wear behavior of chopped Jute fibre-reinforced polypropylene composites, Wear, 261, 2006, 1057-1063.
17. E. Colling, S. Cozien-Cazucc, S.R. Colesa, J. Meredith, R. Powe, B. Weager, Static and dynamic properties of flax and Cordenka epoxy composites, Composite Science Technology, 2013.
18. N. Chouw, L. Yan, Natural FRP tube confined fibre reinforced concrete under pure axial compression: a comparison with glass/carbon FRP, Thin walled structure, 2014.
19. T. NarendiranathBabu, D. Ramaprabha, Dry sliding wear characteristics of Biaxial Glass Fiber with Epoxy/Al_2O_3/Sic hybrid Composites, International Journal of ChemTech Research, 8, 3, 2015, 1175-1183.
20. T. NarendiranathBabu, T. Manvel Raj, D. Rama Prabha, Sliding wear characteristics of Basalt Fiber with GE/Epoxy/Al2O3/Sic hybrid Composites for Journal bearing material using Fish Oil Lubricant, International Journal of ChemTech Research, 8, 4, 2015, 2019-2028.
21. T. Narendiranath Babu, D. Ramaprabha, Sliding wear characteristics of Biaxial Glass Fiber with Epoxy/Al_2O_3/Sic hybrid Composites for journal bearing liner using Sea Water Lubricant, International Journal of ChemTech Research, 8, 4, 2015, 2029-2038.
22. T. NarendiranathBabu, Ditto Ramesh, D. Rama Prabha, T. Lavanya, Wear Behaviour of Hybrid Composite of Basalt Fiber with Titanium Oxide, Barium Sulphate and Silicon Carbide, International Journal of ChemTech Research, 8, 4, 2015, 2053-2062.
23. T. Narendiranath Babu, Ditto Ramesh, D.S. Suryavishnu, D. Rama Prabha, Prediction of Tensile strength on Hybrid Composite of Basalt Fiber with Titanium Oxide, Barium Sulphate and Silicon Carbide, International Journal of ChemTech Research, 8, 6, 2015, 216-224.
24. T. Narendiranath Babu, T. Manvel Raj, D. Rama Prabha, Friction Behaviour of Hybrid Composite of Basalt Fiber with Titanium Oxide, Barium Sulphate and Silicon Carbide, International Journal of ChemTech Research, 8, 7, 2015.