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SPECIFIC WEAR RATE OF EPOXY RESIN BASED COMPOSITES REINFORCED WITH NATURAL FIBERS AND UNI-AXIAL GLASS FIBERS FOR BIO MEDICAL APPLICATIONS

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ABSTRACT

In recent times the concern for the environmental pollution and the prevention of non-renewable and non- biodegradable resources has promoted research in the field of green technologies, eco friendly, non polluting materials which can maximize energy and resource savings. In the present work Jute fibres reinforced with biaxial glass fibres in epoxy matrix, alongside Banana fibres reinforced with biaxial glass fibres in epoxy matrix and Flax fibres reinforced with biaxial glass fibres in epoxy matrix was prepared and mechanical properties were evaluated and compared for two weight fractions, the samples were prepared by using the hand lay-up process and applying pressure at room temperature. The samples were subjected to tribological testing was performed on the samples to investigate the wear properties and to suggest a material which could compete with synthetic materials and still be easily disposed. Results of wear test showed that with increasing reinforcement concentration the wear rate decreases but with increasing speed, sliding distance the wear increases, additional interesting observation was that banana hybrid composite showed less wear than all the other composites.

Key words: Banana fibres, biaxial glass fibres, flax fibres, epoxy resin, wear behaviour.

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1. INTRODUCTION

Presently the world is facing a tough time due to large amount of pollution, increasing levels of CO_2 emissions and as a result of which the environment is deteriorating. Hence natural fibre composites do play a suitable role here. Natural fibres are eco-friendly, renewable, possess good strength and stiffness; have good sound absorption capacity and excellent thermal properties

Benyahia et al [1] studied that removal of lignin, hemi cellulose by alkaline treatment resulted in a rougher surface, which in turn favored mechanical interlocking and bonding reaction due to the exposure of hydroxyl group in the matrix which in turn increased mechanical adhesion. Vivek et al [2] found out that hardness of the composite increases with the increase in fiber loading. The more the fiber volume fraction, higher the modulus of the composite and also did infer that higher the volume fraction of the fiber the impact transfer on the composite sample will be efficient

Pradeep Kumar [3] et al suggested that addition of jute increases the wear resistance of the composite sample and results in decreasing of the coefficient of friction values by 3.5-4.5% and a decrease in 65% of the value of specific wear rate. Compression moulding was used for the manufacture of the jute propylene composites. He also concluded that the effect of the reinforcements was very little on the value of the coefficient of friction. M Jawaid[4] et al observed the chemical resistance of jute fiber reinforced composite and the influence of void formation on the mechanical properties of the composite which proved better adhesion and mechanical properties of hybrid fibers. It was also concluded that the jute fabric layer on the outer surfaces did hold maximum of the tensile strength while the oil palm core absorbed maximum of the stresses and in such a way Jute overlapping the EFB fibres were better than EFB overlapping Jute.

Hanna Brodowsky[5] et al found out that the presence of a coupling agent with the resin in the composite stimulated the adhesion in the interphase of the fiber and the matrix through chemical bonding. The interphase even though it occupies a small volume of the composites still it greatly influences the mechanical properties and therefore chemical bonding around the inter phase region greatly improved their properties. R.A. Braga[6] et al studied through experiments that in order to improve the mechanical properties of the composite hybrid reinforcement was used which involved hybridizing jute with glass fiber as a result the tensile strength of the composites increased, but there was no observable change in flexural strength or the impact energy and the composites with more of jute fibers absorbed more water than the one with high percentage of glass fibers. M Ramesh et al [7] observed that treated banana fibers have a higher degree of adhesion and bonding ability with the hydrophobic resins, also that the percentage of weight loss is lower in the case of treated banana fibers when compared to untreated fibers and he concluded by stating that 60% epoxy with 40% of banana fibers have highest load bearing capacity. He also observed via SEM analysis that chemically treated banana had good adhesion and better bonding and had a high crystalline index.

Alavudeen et al [8] applied that the orientation of the banana fibers also affects their properties. Maximum increase in mechanical properties was observed in the case of plain woven banana fabric when compared with random orientated fibers. It was also observed that the strength of kenaf fibre reinforced composites were better when compared to banana fibre hybrid composite. Irrespective of whatever the fibre was used plain woven fibre composites showed better properties than the twill woven fibre composites. The tensile strength of the composite is more when the fibres are oriented in longitudinal direction. K Senthil Kumar et al [9] studied the vibrational behaviour of banana fiber reinforced composite, and observed that skin core type oriented treated fibers exhibited better properties when compared to skin eccentric type. Accordingly V.P. Arthanarieswaran et al [10] states that adding 2 layer of glass fibers can improve the tensile strength by 2.34 and 3 layer of glass fibers can improve it by 4.13 times. Ebrahim et al [11] performed that Banana plant waste, as lignocellulosic fiber, was treated with alkaline pulping and steam explosion to produce banana fibers and banana microfibrils. And chemical composition of the ensuing fibers and micro fibrils was determined. Addition of treated lignocellulosic fillers after extraction from the banana plant improved the properties of polyethene by 20% addition of fillers, but for any other concentration of fillers it seemed to lose its properties. Yan Li et al [12] studied the voids formation mechanisms and their effects on the mechanical properties of flax fiber reinforced epoxy composite. Effects of processing parameters, including curing pressure, time and temperature on the distribution, shape and content of the voids formed during the manufacturing process were studied.

Liang Huang et al [13] studied that in reinforced Concrete Beams Strengthened with Externally Bonded Natural Flax FRP Plates both ductility and energy absorption capacity increases with FRP strengthening and the plates show same yielding mode as of steel hence can be used in construction and masonry applications. Jiaxin Chen et al [14] presented the nonlinear flexural behaviour of flax FRP double tube confined coconut fibre reinforced concrete. Chand et al [15] analyzed the wear properties of jute fiber reinforced polypropylene in the presence of a coupling agent, the coupling agent that they used was MA-g-PP and this coupling agent had significant effect on the wear properties of the PMC composite, the PMC with the coupling agent showed a higher degree of wear resistance than that which was not.

Meredith et al. [16] studied that the natural fibre composites can be used for high performance structural applications. The experimental composites were fabricated using plain woven flax and regenerated cellulose fibre impregnating it in epoxy resin for evaluating it's mechanical and static structural properties. From the work it was evident that natural fiber reinforced polymer composites could be well used for structural applications but certain more advancements in the experimental work is required to implement it in regular use.

So, here in the project we are performing the comparative analysis to predict so as to which hybrid matrix would be suitable for which applications and also to study the influence of various parameters on the mechanical and tribological properties of the composite.

The major objectives of this research work are

- To study the influence of glass fibre hybridization with the natural fibres in the matrix. The increase is concentration of glass fibres in the hybrid composite would surely increase the density, tensile strength, impact energy stored in the sample but the real investigation is by how much, so the influence of glass fibre is to be studied.
- To design a smart composite material which are highly competitive to synthetic materials in terms of wear and durability. Thereby improving the existing technologies and leading a good quality life in a clean environment.
- To provide a composite that is green and does not deteriorate the environment. There are several legal rules and regulations on protecting the environment. The government of the country is also stressing on the need to safeguard the environment and hence the green composite greatly supports the stand.

- To manufacture the composite material that is easily recyclable which would reduce wastage. The whole agenda of this thing is recycling the waste products into a product which can be used regularly. Just as Banana and Jute is a waste product but it can be used for automotive seating and noise isolation system.
- To provide the best optimum material for the said application this could lead to material savings.
- Reducing the cost incurred by people as in transportation and fuel cost. Designing natural fibre composites with the urge to reduce the overall weight of the automobile because natural fibres have high strength to weight ratio, which will in turn increase the mileage and reduce fuel consumption.
- Incorporating composites in real life scenario like carbon fibre rackets, running shoes, furniture, cots and door panels, etc. could be easily replaced by natural fibre composites which do possess the desirable properties and are economical.
- To study the influence of various properties influencing the wear rate like volume fraction of reinforcement, load, speed, sliding distance and to come out with the result so as to which factor dominates the wear rate.
- To compare the best of the three hybrid composites for mechanical properties as well as the best composite for the tribological properties.

2. MATERIAL COMPOSITION

Table 1 Weight concentration of different constituents in jute hybrid composite.

S No.	Jute fiber % (w/w)	Glass fiber % (w/w)	Epoxy resin % (w/w)
1	10	10	80
2	15	15	70

Table 2 Weight concentration of different constituents in flax hybrid composite.

S No.	Flax fiber % (w/w)	Glass fiber % (w/w)	Epoxy resin % (w/w)
1	10	10	80
2	15	15	70

Table 3 Weight concentration of different constituents in banana hybrid composite.

S No.	Banana fiber % (w/w)	Glass fiber % (w/w)	Epoxy resin % (w/w)
1	10	10	80
2	15	15	70

So for achieving this goal this paper was subdivided into 3 areas of interest:

- Material Selection and Research
- Fabrication
- Testing & Analysis

2.1. Material Selection and Fabrication

- Firstly analysis on the type of matrix which will be incorporated i.e. thermosets or thermoplasts.
- Then under thermosets which matrix to be used, there are several options available i.e. polyester resins, epoxy resins,etc. Epoxy is very widely used for polymer matrix composites and hence epoxy is taken into account.

- Then accordingly selection of natural fibers is done on the basis of their properties, availability, cost and sustainability.
- On the basis of the above factors 3 natural fibers were selected Jute, Banana and Flax.
- Then the question of procurement of the fiber and the resin comes. Resin and glass fibers are purchased from a dealer in Chennai Shakti Glass Fibers, Jute and Flax fibers from local shops in Vellore and Banana fibers were purchased from Coimbatore.

2.1.1. Fabrication

- For fabrication treatment of natural fibers with alkali was necessary hence 10% NaOH solution was purchased.
- Purchasing releasing spray to prevent the resin from sticking to the mould.
- Creation of the mould according to the sample dimensions, for the mechanical tests a rectangular slab was created and the samples were cut according to the dimensions from the slab
- For the tribological testing double tube hot water pipe was purchased to make the samples.

2.1.2. Material Requirement

The material required for this project is 3 different natural fibers: jute, banana and flax. Along with synthetic uniaxial glass fibers. The resin used is epoxy 556 and Araldite hardener ly 556. These materials are used for making the composite.

2.1.3. Sample Preparation

Firstly the natural fibers were treated with 10% NaOH solution which removes the lignin and hemicellulose layer on the fibers. The fibers are then dried in the sun and then washed with soft water then left to dry for a day. Then the fibers are compressed under a uniform load in order to give a uniform thickness. Then Epoxy and hardener are mixed in the ratio 10:1 and then mixed thoroughly to ensure that the mixture is well mixed. Then pouring time is allowed for 10 mins before a layer of mixture is applied in the mould. Then a layer of releasing agent is applied in the mould so that the sample could be easily removed from the mould. Then alternate layers of glass and natural fibers are applied in between the epoxy layers to ensure that a thickness of 4 mm is obtained. Then uniform load is applied on the sample so that the epoxy layer impregnates the fiber layers and a compact bonding is achieved. Then the sample is left to cure for 24 hrs in normal ambient conditions. Similarly samples are made for testing the tribological properties of the natural composites instead circular hot water pipes were used for moulding purpose.

2.1.4. Testing and Analysis

- List of all the equipments and set ups required for testing the samples and getting information about them.
- Cutting the samples according to the dimensions and verifying it with the standards.
- Analyzing the results and comparing it with the standard mathematical results obtained from theories.
- Formulation of design of experiments to come up with a generalized solution of wear rate of natural fiber composites.

2.2. Material Specifications

Table 4 Sample numbers with their corresponding 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 5 Properties of different natural fibers.

Type	Density (g/cm³)	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

Table 6 Properties of cured Epoxy 556 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 MPa

3. DESIGN APPROACH AND DETAILS

3.1. Design Approach

3.1.1. Designing the mould and calculation of the various constituents

- For the samples for mechanical testing a rectangular slab was made from which samples of various dimensions for the testing were cut out.
- The dimensions of the slab was 200 mm * 120 mm * 5 mm, therefore the volume of the slab being 120 cm³.

- The density of epoxy is 1.18 g/cm³ which would occupy 80% according to Sample with 20% fiber volume fraction.
- Therefore the mass of epoxy to be used comes exactly to be 113.28 gm which is rounded off to 115 gm, therefore the weight of glass fibers and the natural fibers in this case for 20% would be 14 gm of both the fibers respectively.
- Same procedure is carried out for 30% of the fiber volume fraction too.
- Calculations for wear test specimens are based on volume of cylinder with radius 10 mm and height 40 mm.
- The mass of epoxy used in this case is 3 gm per sample for 20% fiber volume fraction, therefore the weight of glass fibers and the natural fibers in this case for 20% would be 0.4 gm of both the fibers respectively.
- Same procedure is carried out for 30% of the fiber volume fraction too.

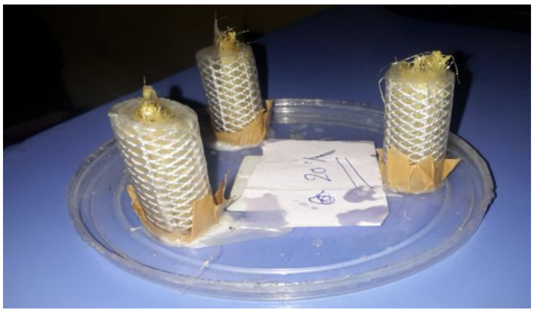

Figure 1 Mould for wear test samples

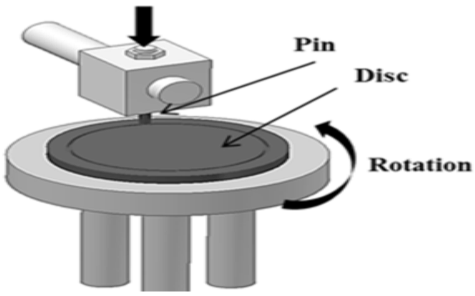

Figure 2 Pin on disc wear test setup

3.1.2. Specifications of Pin on Disc Test Wear Test Setup

ASTM G99 standard test method
Specifications of: ASTM G99
Sliding Speed Range: 0.26-10 m/sec
Disc Rotation Speed: 100-2000 rpm
Maximum Normal Load: 200 N
Frictional Force: 0-200 N
Wear Measurement Range: 4 mm
Pin Size: 3-12 mm diagonal/diameter
Disc Size: 160 mm x 8 mm thick
Wear Track Diameter: 10-140 mm

3.1.3. Synthesizing the Composite Samples

- Firstly the natural fibers were treated with 10% NaOH solution which removes the lignin and hemicelluloses layer on the fibers.
- The fibers are then dried in the sun and then washed with soft water then left to dry for a day.
- Then the fibers are compressed under a uniform load in order to give a uniform thickness.
- Then Epoxy and hardener are mixed in the ratio 10:1 and then mixed thoroughly to ensure that the mixture is well mixed.
- Then pouring time is allowed for 10 minute before a layer of mixture is applied in the mould.

- Then a layer of releasing agent is applied in the mould so that the sample could be easily removed from the mould.
- Then alternate layers of glass and natural fibers are applied in between the epoxy layers to ensure that a thickness of 4 mm is obtained.
- Then uniform load is applied on the sample so that the epoxy layer impregnates the fiber layers and a compact bonding is achieved.
- Then the sample is left to cure for 24 hrs in normal ambient conditions.
- Similarly samples are made for testing the tribological properties of the natural composites instead circular hot water pipes were used for moulding purpose.

ASTM G99

- ASTM G99 standard was taken into account for testing the tribological properties of the Hybrid Polymer matrix Composite. Specimen diameter 10 mm and length 30 mm for different parameters like load, speed, sliding distance, etc. can be tested.
- Mould for the mechanical sample testing, we employed anabond silicone releasing spray before pouring the epoxy into the mould but still some portions of the epoxy was still in contact with the mould making the specimens a bit deformed and rough after removing from the mould. So we decided to lay the interior of the mould with plastic cello tape as a result of which the epoxy did not bond to the smooth cello tape layers and the removal of the slabs from the mould was easy and it had a great surface finish.
- For preparing the wear test specimens firstly a mould out of plaster of paris was made with the specified mould cavity according to the sample dimensions but after pouring the epoxy resin it was observed that epoxy would infuse through the plaster of paris and leaving the fibers dry, so we used 10 mm diameter hot water pipes for making the mould pipes of the length 4 cm were cut and then epoxy was poured from the sides followed by inserting the fibers and then again pouring the epoxy throughout the cavity.

4. RESULTS AND DISCUSSIONS

4.1. Tribological Tests (Wear Test)

There are several set ups which can be used for conducting wear tests some of them are dry sand rubber wheel, pin on drum, linear tribo machine, block on ring, block on disc and pin on disc. For our purpose we have used the pin on disc set up. ASTM G99is the standard for pin on disc testing. The sample is 10 mm in diameter and 30 mm in length. The sample is subjected in a perpendicular direction against a rotating counter face. The contact with the counter face continuously erodes the material and the wear and the frictional force acting is continuously measured with the help of sensors fitted on the set up. Care should be taken while applying and removing the loads and fluctuations in the load will bring a lot of error in the test.

In our case we have taken readings against three different rpms (300,400,500) rpm against 3kgf load. And even we have tested it against different sliding distances. And wear graphs were plotted and alongside graphs for coefficient of friction and specific wear rate is also provided.

Sliding distance of 1 km, 1.5 km and 2 km was calculated using the formula

$\omega = 2*\pi*N/60$

Here N=400 rpm

Therefore ω = 41.87 rad/s

V = rω, r = 75 mm

V=1.57 m/s. Therefore, time taken to cover 1 km,1.5 km and 2 km distance are 10.6 mins, 16 mins and 22 mins.

Hence for the sliding distance the machine was adjusted to a time limit of 22 mins

And the specific wear rate was calculated using the formula:

Specific wear rate = $(\Delta m)/\rho FL$

Where Δm stands for change in mass and ρ for the density, F for the normal force acting or the load acting and L is the distance travelled or slides.

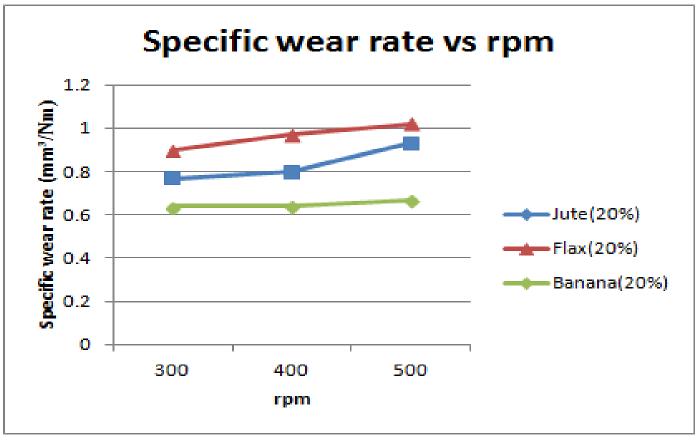

Figure 3 Specific wear rate vs rpm for 20% hybrid composites for 1 km sliding distance and 3 kg load

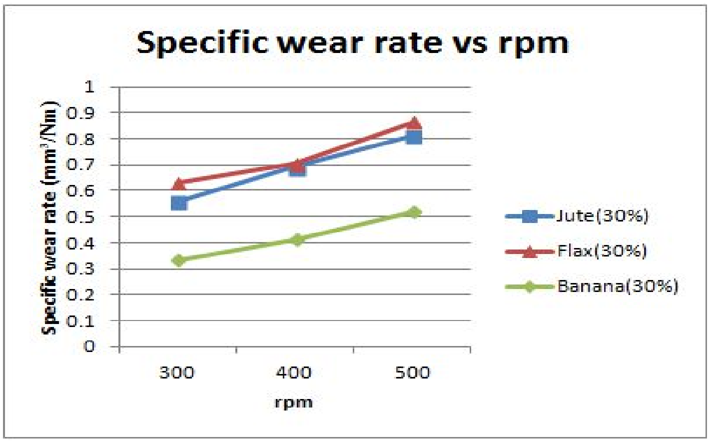

Figure 4 Specific wear rate vs rpm for 30% hybrid composites for 1 km sliding distance and 3 kg load.

Table 7 Values of specific wear rate for 20% hybrid composites for 1 km sliding distance and 3 kg load.

Type	Specific wear rate x 10^{-3}		
	300	400	500
Jute	0.77	0.798	0.931
Flax	0.9	0.97	1.02
Banana	0.638	0.643	0.665

Table 8 Values of specific wear rate for 30% hybrid composites for 1 km sliding distance and 3 kg load.

Type	Specific wear rate x 10^{-3}		
	300	400	500
Jute	0.5586	0.6916	0.8113
Flax	0.633	0.705	0.8645
Banana	0.3325	0.4123	0.5187

Table 9 Values of specific wear rate for 20% hybrid composites for 400 rpm and 3 kg load

Type	Specific wear rate x 10-3		
	1	1.5	2
Jute	1.33	0.975	0.75
Flax	1.38	1.006	0.79
Banana	1.118	0.886	0.678

Table 10 Values of specific wear rate for 30% hybrid composites for 400 rpm and 3 kg load

Type	Specific wear rate x 10^{-3}		
	1	1.5	2
Jute	1.064	0.7323	0.5586
Flax	1.17	0.8066	0.61845
Banana	0.8246	0.603	0.4788

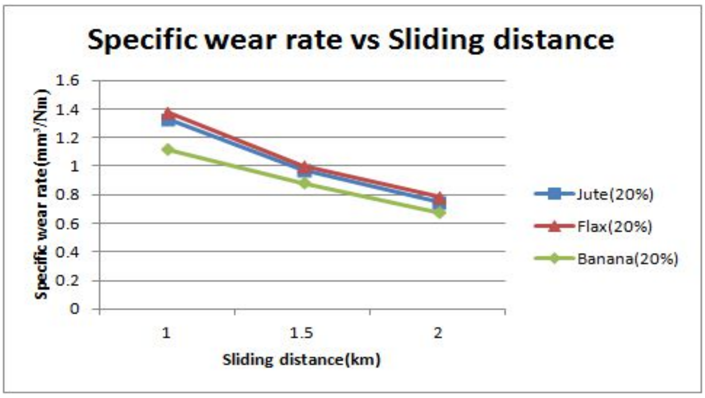

Figure 5 Specific wear rate vs sliding distance for 20% hybrid composites at 400 rpm and 3 kg load. rpm and 3 kg load

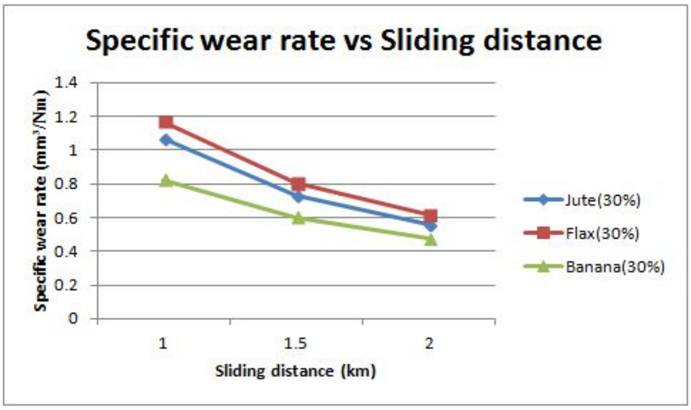

Figure 6 Specific wear rate vs sliding Distance for 30% hybrid composites at 400 rpm and 3 kg load.

According to the values in the table and trends in the graph for Specific wear rate vs speed it is clearly evident that the specific wear rate will increase as because for same load and sliding distance with increase in speed the composite wears more, but in case of Specific wear rate vs sliding distance the value decreases with the increase in sliding distance.

- with increasing the fibre content from 20% to 30% the wear rate of the material decreases.
- With increasing the speed wear rate increases for the same fiber content.
- Composites with normal orientation of the fibers against the sliding direction have best wear rates than parallel or anti-parallel directions.
- Coefficient of friction increases the volume fraction of the composites and results in lower wear.
- Increase in surface temperature due to thermal softening can increase the wear rate of the composites.
- For the same speed and same amount of load different composites behave differently i.e. maximum wear was observed in the case of flax and minimum in the case of banana.
- Banana has the lowest specific wear rate and would be better if considered for tribological applications in rotating and sliding parts.

5. CONCLUSION

This paper focuses on comparing the mechanical and tensile properties of three natural fibers hybridized with glass fibers. The testing and experiments were performed on the samples in order to classify their properties, a total of friction and wear tests have been performed. The results from the wear test suggests that banana hybrid composite has the lowest specific wear rate and would be better if considered for tribological applications in rotating and sliding parts. In all the cases jute hybrid composite performed mediocrely and hence because of it's ease in availability, it is cheap so can be used for medium duty purpose. Alternative that could be suggested is for the wear test is that the presence of a coupling agent could greatly reduce the wear and make the natural fiber composite easy to deploy in tribological fields and hence this could be adopted for some biomedical applications.

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