OPEN ACCESS
International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-10 Issue-1, May 2021

Effect of Graphite Addition on Mechanical and Tribological Properties of Sisal–Glass FRP Composites

Suresh Kumar. D, Sanjeevamurthy, G. Mallesh

Abstract*: Composite materials are gaining more importance in present-day engineering design and development activities because of their attractive mechanical properties [1-2] and are composed of Fibers, Matrix and Fillers. In the present research work Glass and Sisal are used as fibers, Epoxy resin is used as a matrix and different volume fractions of graphite is used as a filler to develop FRP composites using hand layup and bag molding process to study the Mechanical and Tribological characteristics as per ASTM standards. It is evident from the results that Mechanical properties are improved marginally compared to unfilled composites. Further, it is noticed from POD and three-body abrasive tests that the addition of the Graphite enhances the coefficient of friction with the reduction in wear loss. Due to environmental consciousness, interest in the use natural fiber are enhanced in different applications. A comparative study was conducted between synthetic (Glass) and natural (Sisal) FRP composites filled with graphite for automotive brake material.

Keywords: Sisal, Glass, Graphite, FRP composites, Mechanical and Tribological Characteristics

I. INTRODUCTION

Composites are the amalgamation of two or more materials which are different in form and chemical constituents. These are more predominant in the present design process because of attractive physico-mechanical properties and have potential to replace the conventional materials in various fields of engineering.

Glass, Carbon, Natural and Aramid fibers are used in the FRP industry along with different reinforcements to serve a wide range of processes and end-product requirements. Natural fibers aren't the newly discovered material, human beings are habituated to the use of natural fibers from ages, in form of shelter and clothing (Cotton clothes, wool etc.). Natural fibers hold the feature of being eco-friendly and it does possess appreciable mechanical and physical properties. Natural fibers besides mechanical and physical properties also show notable characteristics like toughness, non-toxicity, recyclability, easy accessibility, affordability etc.

Fillers are used to impart special properties and to lower the cost of composite by diluting costly resins and minimizing the quantity of reinforcements. Commonly used fillers are Calcium carbonate, Alumina trihydrate, Hydrous Aluminum silicate, Carbon, Calcium sulphate, Graphite etc.

The task of matrix in the composite is to hold reinforcement together, Phenolic and Epoxy resins (ER) are commonly used to manufacture FRP composites because of their versatility, low shrinkage and excellent adhesive properties with minimum cost.

Therefore, in the present context, Epoxy resin, Glass fiber (synthetic) and Sisal fibers (natural) are reinforced with 5, 10, 15 wt.% of Graphite is used to develop and evaluate Tribo-Mechanical properties of synthetic and natural FRP composites.

II. LITERATURE SURVEY

Literature survey is the foundation of any research work. Data from the literature articulates procedure, characterization and evaluation of an experiment. Data collected from the literature is acknowledged and implemented in the present work.

Yasmin., et al [1] developed epoxy (DGEBA) reinforced with 2.5-5 wt.% graphite. It is evident from the results that addition of graphite enhances tensile strength and elastic modulus of the composites and the coefficient of thermal expansion decreases the storage modulus of the composites with the addition of graphite concentration.

Patnaik., et al [2] fabricated multi component Glass-Epoxy hybrid composite using SiC, pine bark dust fillers. It is noticed that addition of the fillers increases Flexural, Tensile and Impact strengths of the composites. Further, density, micro-hardness and flexural properties of the composites were improved due to the addition of hard SiC particles compared to pine bark dust fillers.

Rajasekar et al [3] evaluated the mechanical properties of styrene butadiene rubber (SBR) and epoxidized natural rubber (EPR) Nano-clay composites.

Manuscript received on May 17, 2021.
Revised Manuscript received on May 25, 2021.
Manuscript published on May 13, 2021.

* Correspondence Author

Suresh Kumar. D*, Assistant Professor, Department of Mechanical Engineering, Government Engineering College, Hassan, India. Email: suavik@gmail.com

Dr. Sanjeevamurthy, Professor, Department of Mechanical Engineering, Sri Siddhartha Institute of Technology, Tumkuru, India. Email: hodmechssit@gmail.com

Dr. G. Mallesh, Professor, Department of Mechanical Engineering, Sri Jayachamarajendra College Engineering, JSS S&T University, Mysore, India. Email: mallesh@sjce.ac.in

Results revealed that storage modulus of rubber compounds containing dual filler improves the mechanical properties and SEM images shows rough and irregular fracture paths due to the physical interaction between filler and rubber.

Bhagat et al [4] studied the effect of Graphite filler by varying the weight fraction on mechanical behavior of epoxy composites. It is observed that addition of 2-8 wt.% of filler content shows the improved flexural, tensile modulus and impact strength.

Raju et al [5] investigated the Mechanical and Wear behavior of Al2O3 particulate filled Glass fabric reinforced Epoxy composites. It is observed that addition of Al2O3 exceptionally improves the mechanical properties such as tensile modulus, strength, and hardness properties of G-E samples. Further, addition more than 10 wt.% Al2O3 exhibits excellent wear resistance.

Akın et al [6] developed carbon fiber (CF) and expanded graphite (EG) filled cyclic olefin copolymer composites to study the electrical and mechanical properties. It was observed that CF and EG can be successfully dispersed into the polymer phase via melt processing in a twin screw extruder without an extra component, a polymeric compatibilizer. Further noticed electrical conductivity and mechanical properties are enhanced by addition of EG.

Shokrieh et al [7] studied the Mechanical and Tribological performance of the epoxy composites with the addition of graphite filler/ date palm fiber. Result indicated that mechanical properties of date palm fiber are improved in comparison with epoxy composites. Further, it is noticed that NaOH treated date palm and graphite improves the hardness and mechanical properties of the composite.

Baptista et al [8] Fabricated Graphite/Epoxy reinforced Carbon fiber to study the Mechanical and Tribological properties. of composites. It is evident from the results that addition of the Graphite showed improved elastic, shear and flexural modulus. The presence of graphite in the epoxy leads to wear resistance because graphite acts as a lubricant in the composites.

Wang et al [9] studied the effect of Al2O3 contents on mechanical and fracture properties of Carbon-Epoxy fiber reinforced composites. Results revealed that Fracture toughness, Impact strength and Flexural properties were enhanced with the addition of micro- Al2O3 particulates. Additionally, it is noticed that addition 15 g/m2 Al2O3 particles enhances mechanical and fracture characteristics.

Suresha et al [10] developed the bi-directional Jute fabric reinforced Epoxy (J/Ep) filled with 2.5, 5, 7.5 and 10 TiO2 wt.% particles to study the mechanical performance. It is evident from the results that mechanical properties of the J/Ep composite enhanced due to addition of TiO2 particles up to 7.5 wt. %. Later, abrasive wear tests were conducted using POD and 3-Body abrasive wear testing machine and results confirms that addition of TiO2 resist wear of the composites and from the SEM micrographs fiber and filler have fairly good bonding with matrix.

Kumar et al [11] polypropylene reinforced composites were manufactured using 10%, 20%, 30% & 45% of slag filled composites by injection molding process to study the friction and wear behavior on POD wear testing machine by varying sliding velocity and applied load. Results were plotted to know the wear loss and coefficient of friction and noticed that as the filler increases wear loss decreases.

Biswas et al [12] Taguchi's approach was taken to conduct parametric analysis on erosive wear behavior for short bamboo fiber reinforced epoxy composites filled with copper slag. Different factors like impingement angle, impact velocity, fiber loading and stand-off distance were analyzed

and found that 60°impingement angle has major effect on erosion rate.

From the available literature it is observed that many researches are worked towards the development of lightweight materials for engineering applications using various fibers, matrix and different wt.% of fillers. A limited attempt is made to develop natural fiber reinforced composites. Hence, in this research work attempts are made to develop synthetic and natural fibers to compare the effect of addition of graphite reinforcement.

III. MATERIALS AND METHODS

A. *Material and Fabrication of FRP Composites*

A composite sheet of (250 x 250 x 3.2) mm thick is fabricated with the help of hand layup and bag molding process for 5,10 and 15 wt.% of Graphite powder reinforced with Glass/Sisal fiber and Epoxy resin as shown in Figure.1.

Mass of Glass/Sisal fiber, Epoxy resin and mass of the Graphite were calculated as per their volume and density as shown in Table 1.

Figure 2 shows the various stages of the fabrication process. Initially number of layers of the Glass/Sisal fibers are marked and cut from the Glass/Sisal mat strands with the help of marker and scissors, number of layers are chosen based on the thickness of the laminate.

Table: 1. Density of Materials

Materials	Density (ρ) kg/m^3
E- glass	2.54
Sisal	2.55
Epoxy resin	1.15
Graphite powder	2.26

In the next step, calculated mass of Epoxy resin along with hardener are mixed with the Graphite powder. Initially, a layer of the Glass/Sisal fiber are placed on clean and flat surface. First layer is coated with a layer of resin using a brush and continued till to get the required thickness of a laminate.

Further, breather and perforated sheet are used to remove the excess resin by creating vacuum in order to remove the excess resin and air trapped in between the layers. Curing of the composite plate is carried out at 1000C by an hour. Post curing was done at 80ºC for about 24 hours in a hot air oven to ensure the complete curing of composite laminates. Similar procedure is carried out for different weight fractions of Graphite powder by keeping Glass/Sisal fiber volume fraction constant(30% Weigth Fraction).

Finally, composite plates were cut using abrassive water jet machine as shown in Figure 3. Addition of abrasive particle leads to the quality of the machining process. In this machine a high speed water jet impinge on the work piece which removes material from the contact surface by erosion. Tensile, flexural, Impact and wear test specimens were cut as per different ASTM standards. Figure 4. shows the retained portion of reinforced composite plates after cutting.

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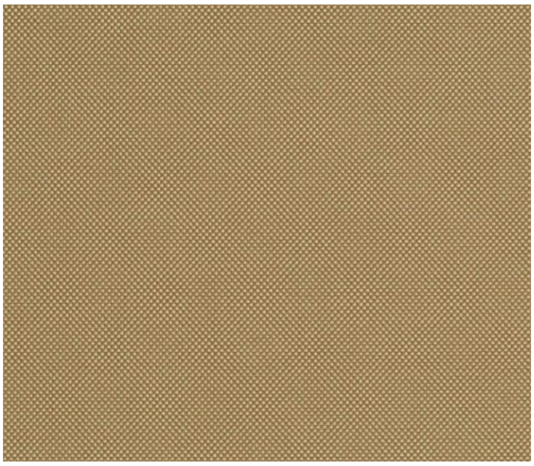
Glass Fiber Mat



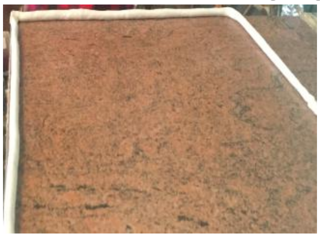
Sisal Fiber Mat

Epoxy Resin with Hardener

Graphite Powder (Particle Size 66 Microns)

Fig: 1. Materials used for fabrication of FRP composites

Weighing of Mixture



Flat Surface

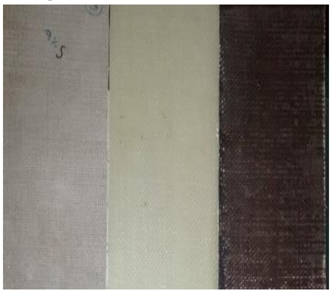
Covering The Glass Fiber

Breather Sheet

Polymer Sheet

Vacuum bag

Post Curing



Composite sheets

Fig: 2. Fabrication stages for FRP composites

B. *Mechanical Characterization*

Owing to the vast research which has taken place in the past three to four decades, the characterizations of composite materials have been found to be important for many applications. In the present study, Glass/ Sisal fibers reinforced with Epoxy resin and filled with Graphite powder composites were tested for Mechanical and Wear properties.

Retrieval Number: 100.1/ijrte.A59420510121
DOI: 10.35940/ijrte.A5942.0510121
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Figure. 3. Abrasive water jet machine

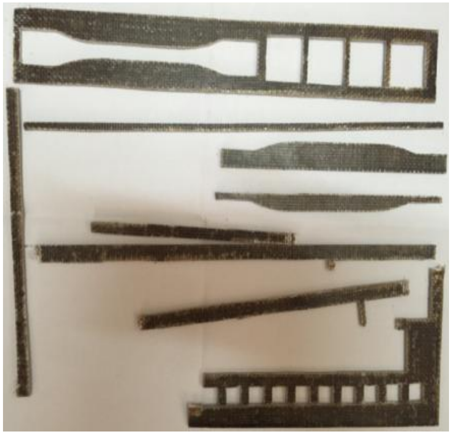
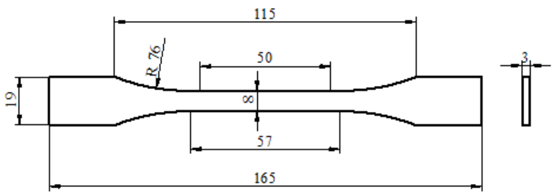
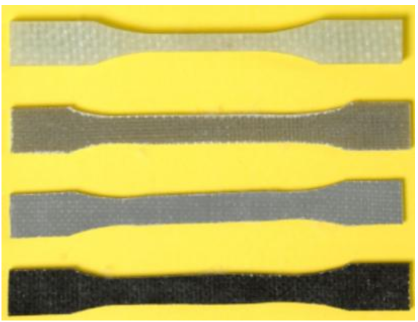


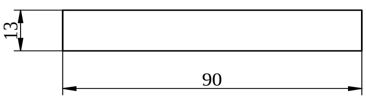
Fig: 4. Retained portion of Graphite filled compostes

A series of tests were conducted as per different ASTM standards shown in Figure 5. To evaluate the Tensile, Flexural and Impact strength. Similarly, Hardness of the composites were measured by the Shore- Durometer (Shore-D) for unfilled, 5%, 10% and 15 wt.% of Graphite, Glass/Sisal reinforced with Epoxy to evaluate the effect of the reinforcement.

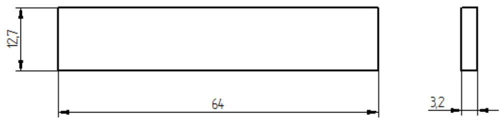




ASTM 790 Tensile test Specimens

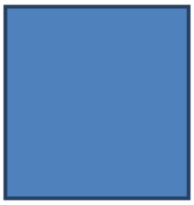


ASTM D790-03 Flexural test Specimens



All Dimensions are in mm

ASTM D 256 Impact test Specimens



(24.5 X 24.5 X 3.2 Thick) mm

ASTM D2240 Hardness test specimens

Figure 5. ASTM Standard Test Specimens

C. *Wear Analysis and Optimization*

Wear involves progressive material loss of the component in contact with the other and are in relative motion. Wear is classified as abrasive, adhesive, erosive, surface fatigue and corrosive wear. In the present study, the dry sliding wear tests were conducted using Pin- On- Disc machine in accordance with the ASTM G 99-95 standard. EN31 hardened steel disc with 62 HRC and 180 mm diameter was chosen for unfilled, 5%, 10% and 15 wt.% of Graphite, Glass/Sisal fiber reinforced with Epoxy as per the Design of Experiments [11-13].

Retrieval Number: 100.1/ijrte.A59420510121
DOI: 10.35940/ijrte.A5942.0510121
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Figure 7. Shows the POD wear test experimental setup, the tests were carried out by varying normal load from10 N to 30 N and sliding velocities of 2, 3 and 4 m/s with sliding distances of 1, 2 and 3 km for different wt.% of graphite. A track diameter of 120 mm was used in all the experiments. The weight loss was determined using electronic balance with accuracy count of 0.0001grams.

5 wt.%

10 wt.%

15 wt.%

Figure 6. ASTM G 99-95 standard wear test Specimens

D. *Optimization Technique*

Optimization is a technique for maximizing or minimizing a real function by choosing the input functions. In general, optimization is a process of finding the "best available" value among the variety of objective functions and domains. Design of Experiments (DOE), Taguchi Technique, and Analysis of Variance (ANOVA) are adopted in the present study.

Dry sliding wear tests were performed as per the design of experiments with four factors at three levels. A standard L_{27} orthogonal array was chosen with twenty-seven rows and thirteen columns [11]. In the present work different wt.% of Graphite reinforced Glass and Sisal fiber reinforced with epoxy material by considering applied load, sliding velocity, percent reinforcement and sliding distance as process parameters as given in Table 2.

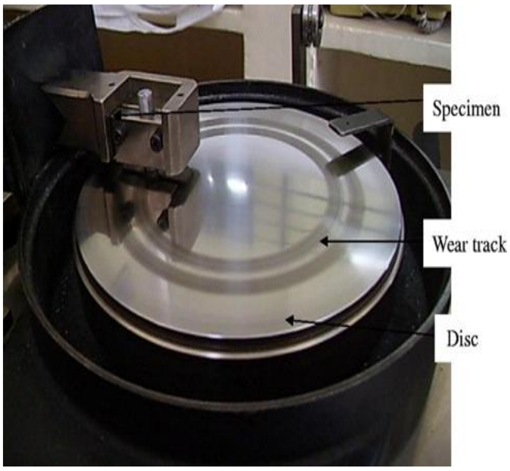

Figure 7. Pin On Disc Setup

Table. 2. Process parameters and their values for L_{27} Array

Level	Wt.% Reinforcement	Sliding velocity(m/s)	Applied Load (N)	Sliding distance(m)
1	5	2	10	1000
2	10	3	20	2000
3	15	4	30	3000

IV. RESULTS AND DISCUSSIONS

A. *Mechanical Properties*

A series of tensile tests were conducted as per ASTM 790 standard on computerized universal testing machine to evaluate the tensile strength of Glass/Sisal, Epoxy and 5, 10 and 15 wt.% of Graphite filled composites. (Figure.8).

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It is evident from the results that addition of the reinforcement in Glass/ Sisal leads to the enhancement of tensile strength by 12, 16 and 18% and 48, 104 and 152% for Glass /Sisal fibers respectively.

The enhancement in the tensile strength is attributed to the proper dispersion, chemical, physical cross links and inter molecular bonding between fiber, fillers and matrix. Further, Sisal fiber have established strong interface adhesion with the addition of graphite therefore sisal fibers tends to have better tensile strength compared unfilled composites.

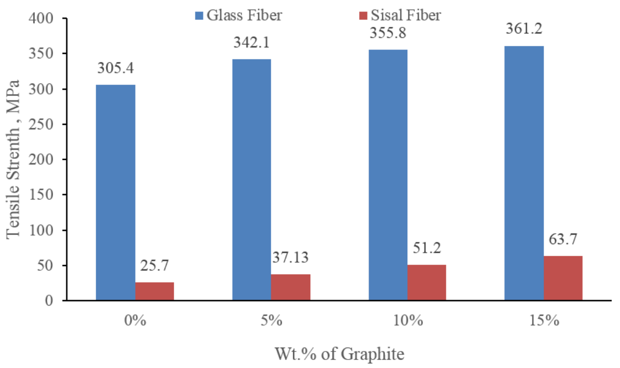

Figure 8. Tensile Strength of Glass/ Sisal FRP composites

Flexural strength of unfilled and Graphite filled composites was conducted. It is evident from the results that addition of the fillers leads to the enhancement of flexural strength. Graphite fillers in the Glass fiber composites has 9, 16 and 40% increase in flexural strength compared to unfilled composites. Similarly, sisal fiber composites have enhancement rate of 38.92, 40.65% and 48.92 % in comparison with unfilled composites [18] (Figure.9).

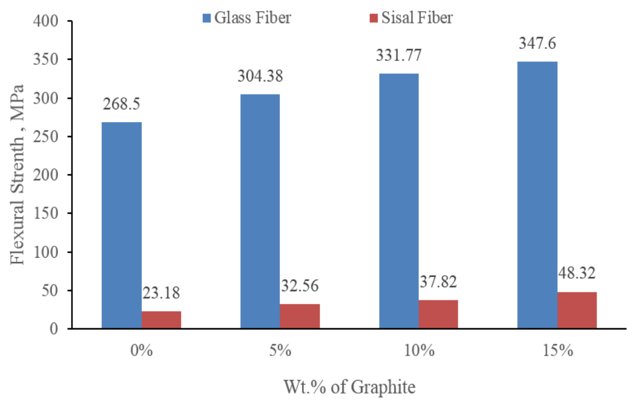

Figure 9. Flexural Strength of Glass/ Sisal FRP composites

Impact strength of the composite material enhances with increase in the wt.% of reinforcement. This is due to better bonding between fibers, binders and additives. Further, impact strength of glass based composite materials were more because glass fibers have better inherent mechanical properties than that of sisal fibers. It is evident from results that the impact strength of glass based composites improved as compared to Sisal based composites [17, 18] (Figure.10)

The Shore D hardness of GF and SF reinforced composites enhanced with increase in filler content. This is due to more resistance offered by the filler as its content increases in the composites. Addition of GF in matrix has resulted in the highest hardness value among the considered composites due to the better mechanical properties of GF compared to SF [19] (Figure.11).

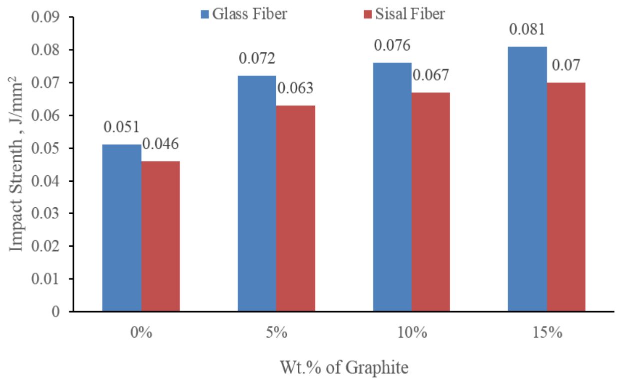

Figure 10. Impact Strength of Glass/ Sisal FRP composites

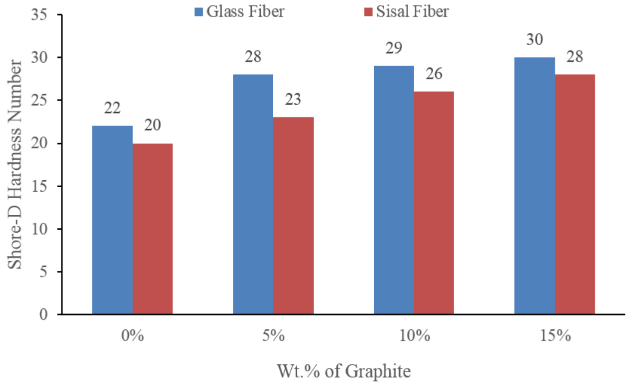

Figure 11. Hardness of Glass/ Sisal FRP composites

B. ***Wear Properties***

Wear tests were conducted using Pin-On-Disc machine as per the design of experiments to determine wear loss of the composites developed. Wear loss for Glass/Sisal fiber reinforced with 5, 10 and 15 wt.% Graphite composite is tabulated in the Table 3.

Table. 3 Experimental results of wear loss using POD.

$L_{27}(3^{13})$ Test		Sliding Velocity, m/s	Load, N	Sliding distance, m	Glass Fiber	Sisal Fiber
1.	5 Wt.% of Reinforcement	2	10	1000	0.2	0.3
2.		2	20	2000	0.3	0.4
3.		2	30	3000	0.4	0.6
4.		3	10	2000	0.6	0.5
5.		3	20	3000	0.7	0.8
6.		3	30	1000	1.2	1.4
7.		4	10	3000	1.9	1.3
8.		4	20	1000	0.8	0.9
9.		4	30	2000	1.2	1.2

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Journal Website: www.ijrte.org

Published By:
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and Sciences Publication

International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-10 Issue-1, May 2021

10.	10 Wt.% of Reinforcement	2	10	1000	0.7	0.8
11.		2	20	2000	1.1	1.3
12.		2	30	3000	1.3	1.7
13.		3	10	2000	1.6	2.1
14.		3	20	3000	1.8	2.0
15.		3	30	1000	1.3	1.3
16.		4	10	3000	1.7	2.1
17.		4	20	1000	1.5	1.7
18.		4	30	2000	1.7	1.9
19.	15 Wt.% of Reinforcement	2	10	1000	1.2	1.6
20.		2	20	2000	1.3	1.5
21.		2	30	3000	1.8	1.9
22.		3	10	2000	1.3	2.1
23.		3	20	3000	1.4	1.9
24.		3	30	1000	1.1	1.7
25.		4	10	3000	1.9	2.1
26.		4	20	1000	1.2	2.1
27.		4	30	2000	1.3	2.0

Results obtained from the POD experiments are used to develop Taguchi analysis, ANOVA and multiple regression models using MINITAB software to establish correlation between significant terms obtained from ANOVA based on reinforcement, applied load, sliding velocity and sliding distance.

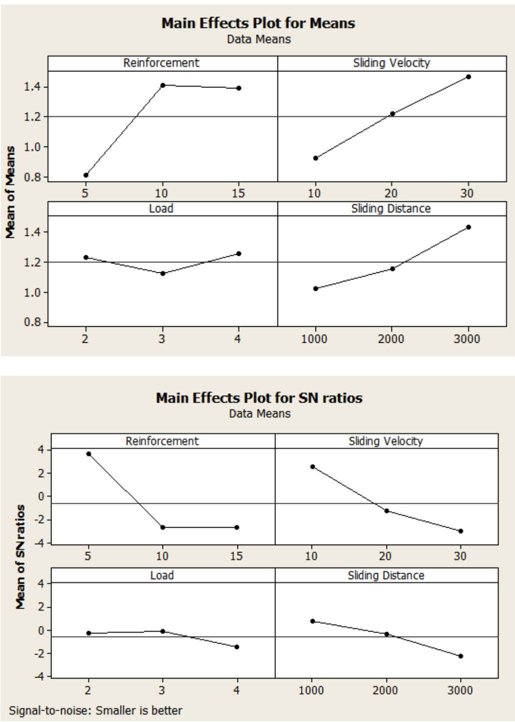

Figure 12. Means of means and S/N ratio plot for Glass fiber

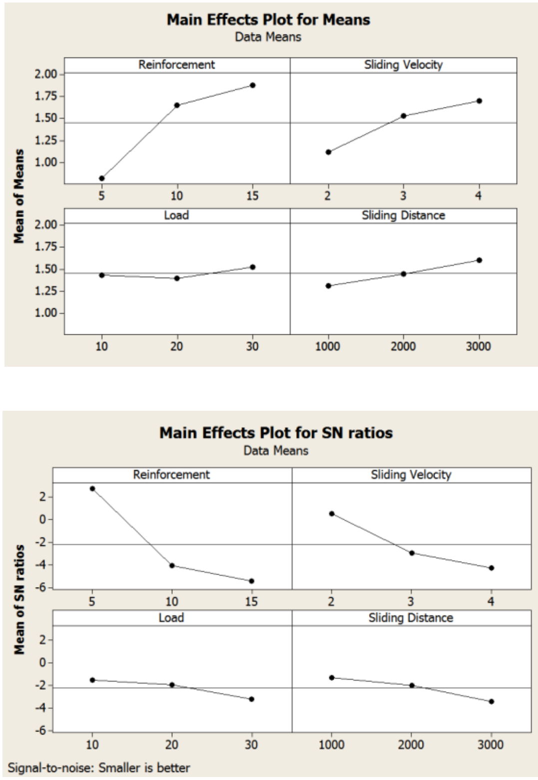

Figure 13. Means of means and S/N ratio plot for Sisal fiber

Figure 12 & 13 shows S/N ratio for the wear effect plots for different process parameters. Parameter showing highest inclination will have the most significant wear rate. From the plot, it is evident form Sisal/Glass FRP composites that wt. %. of the reinforcement is a major influential parameter compared to others.

Table 4. ANOVA results for S/N ratio for Sisal fiber

Source	DF	Seq SS	Adj SS	Adj MS	F	P %
Reinforcement	2	345.65	345.65	172.82	29.38	57.99
Sliding Velocity	2	110.34	110.34	55.17	9.38	18.51
Load	2	13.48	13.48	6.74	1.15	2.26
Sliding Distance	2	20.68	20.68	10.34	1.76	3.47
Error	18	105.87	105.87	5.88		17.76
Total	26	596.04				100

It is observed from Table 4 that, reinforcement and sliding velocity has 57.99 %, 18.51 % influence on wear rate and it clearly shows that as the load increases and friction at contact surface increases with increase in wear rate. Hence, from ANOVA analysis reinforcement have major contribution towards wear rate in comparison with other parameters.

Retrieval Number: 100.1/ijrte.A59420510121
DOI: 10.35940/ijrte.A5942.0510121
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Similarly, multiple linear regression equation is developed using MINITAB software to study the wear loss of Sisal-Epoxy Graphite reinforced composite. It is observed that the positive and negative values of the coefficients of the parameters suggest, that sliding wear increases or decreases with increase in associated variables.

Wear Loss = - 0.848 + 0.106 Reinforcement + 0.289 SV + 0.00444 Load + 0.000144 SD

It is observed from the above equation that, sliding velocity with the magnitude of 0.289 is the highest among all parameters and has more effect on wear of the composite.

Table 5. ANOVA results for S/N ratio of Glass Fiber

Source	DF	Seq SS	Adj SS	Adj MS	F	P %
Reinforcement	2	244.5	244.5	122.25	11.83	38.59
Sliding velocity	2	150.23	150.23	75.11	7.27	23.71
Load	2	9.27	9.27	4.64	0.45	1.46
Sliding distance	2	43.54	43.54	21.77	2.11	6.87
Error	18	186.06	186.06	10.34		29.37
Total	26	633.6				100

Further, similar analysis was conducted for Glass fiber reinforced composite and found from the ANOVA that reinforcement has highest influence on dry sliding wear followed by sliding velocity.

Wear loss = - 0.624 + 0.0578 Reinforcement + 0.272 SV + 0.00111 load + 0.000206 SD

It is observed from the above multiple linear regression equation that, sliding velocity with the magnitude of 0.272 is the highest among all parameters and has more effect on wear of the composite.

A comparative analysis was done to know the effect of reinforcement between Glass and Sisal fiber reinforced composite and found that Sisal FRP composite system has higher tends towards wear loss compared to Glass FRP composites. Even with higher wear it is suggested to use Sisal fiber (natural) in place of Glass because of its ecofriendly and bio degradable nature. Further, addition Graphite is suggested to enhance the mechanical and tribological characteristics of Sisal FRP composites.

V. CONCLUSIONS

Based on the study of the mechanical properties of different wt.% of graphite that sisal fiber epoxy composites, has minimum tensile, flexural and impact strength compared to Glass FRP composites because of poor adhesion between Sisal, Graphite and Epoxy. Further, it is noticed from the tribological results that Sisal FRP composites has more wear compared to Glass FRP composites. Use of natural fiber reinforced composites gaining more importance in many engineering applications, because of its superior properties such as specific strength, low weight, low cost, fairly good mechanical properties, non-abrasive, Eco-friendly and Bio-degradable characteristics. Therefore, it concluded that Sisal fiber FRP composites developed in the research can be used as a friction material in blend with graphite filler.

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AUTHORS PROFILE

Mr. Suresh Kumar. D, is Assistant Professor in the Department of Mechanical Engineering, Government Engineering College, Hassan, Karnataka, India.
He graduated Kuvempu University and obtained his master's degree from Visesvaraya Technological University. He works in the area of Mechanical Engineering with particular reference to studies related to design and Analysis of composite materials using micro structure based finite element analysis.

Dr. Sanjeevamurthy, is Professor in the Department of Mechanical Engineering, Sri Siddhartha Institute of Technology, Tumkur, Karnataka, India.

He graduated from Mysore university and obtained his Master's and Doctoral degree from Mysore University. He works in the area of Mechanical Engineering with particular reference to studies related to design and finite element analysis.

Dr. Mallesh G, is Professor in the Department of Mechanical Engineering, Sri Jayachamarajendra College of Engineering, JSS Science and Technology University Mysore, Karnataka, India, He graduated from the Mysore University and obtained his Master's Degree and Doctoral Degree from Visvesvaraya Technological University. He works in the area of Mechanical Engineering with particular reference to studies related Asymmetric spur gear design and Analysis, Finite Element Analyses, Fatigue and Fracture Analysis of composite Materials using Micro structured based Finite element analysis. He is a Fellow of Institution of Engineers and life member of Tribology Society of India.