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**Suresh Kumar Devendrappa[1]*, Sanjeevamurthy[2], Mallesh Goud[3], Pavankumar Ravikumar[4]
Vasanth Kumar Hasthinapura Seena Naik[5]**

[1] Government Engineering College, Department of Mechanical Engineering, Hassan, India
[2] Sri Siddhartha Institute of Technology, Department of Mechanical Engineering, Tumakuru, India
[3] JSS S&T University, Sri Jayachamarajendra College Engineering, Department of Mechanical Engineering, Mysore
[4] JSS S&T University, Sri Jayachamarajendra College Engineering, Department of Mechanical Engineering, Mysore
[5] Government Engineering College, Department of Mechanical Engineering, Kushalnagar, India
**Corresponding author. E-mail: suavik2020@gmail.com[1]*

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A STUDY ON MECHANICAL AND WEAR BEHAVIOUR OF GRAPHITE FILLED SISAL-GLASS-EPOXY HYBRID COMPOSITES

In recent years, advancements in development of composite materials can be distinctively observed and taking ecological factors into account, researchers are currently working on the development of natural fibre composites for various applications. The current work concentrates on assessment of the mechanical and wear characteristics of sisal-glass (natural and synthetic) epoxy hybrid graphite filled composites. A comparative characteristic study was performed in the study between synthetic (glass) and natural (sisal) FRP composites and it was found that graphite filled FRP composites exhibit excellent tensile properties, flexural modulus enhanced by 35.2%, the hardness and impact strength were improved with the addition of graphite filler. Statistical analysis was conducted using the design of experiments with the help of ANOVA software. From the tribology tests, it was noticed that the COF and wear loss of the composites with the natural reinforcement are comparatively higher than that of the synthetic fibre. It is evident from ANOVA and regression analysis that the reinforcement has 57.99% influence on the wear rate. Due to increased environmental consequences, natural FRP composites are recommended to be used in as automotive brake friction material and aerospace body parts.

Keywords: **mechanical and tribological characteristics, sisal, glass, graphite, FRP composites**

INTRODUCTION

Composites as a material possess very attractive physico-mechanical properties such as high strength-to--weight ratio, higher thermal, wear and corrosive resistance [1]. Due to the rising popularity of advanced materials, conventional materials are replaced by composites.

Composites are the amalgamation of two or more materials which are different in their form and chemical constituents [2]. In composites, Fibre Reinforced Composites (FRC) are among the most promising materials with high flexural strength, durability, stiffness and damping properties [3]. They also offer resistance to corrosion, wear, impact, and fire.

Generally, FRCs are comprised of fibres as reinforcements, resins as the matrix and fillers. Fibres are categorized into natural and synthetic. Natural fibres are those produced by geological processes or derived from the bodies of plants or animals. Synthetic fibres are an end product from chemical reactions between petroleum-based chemicals or petrochemicals [4]. Examples of synthetic fibres are polyester, nylon, polyethylene, Teflon, glass etc.

In fact, synthetic fibres are robust when compared with natural fibres, but natural fibres have an additional feature of being eco-friendly. Natural fibres also exhibit notable characteristics like toughness, non-toxicity, recyclability, easy accessibility, affordability etc.

Chen et al. [5] investigated physical, mechanical environmental and stress cracking characteristics of glass/epoxy fibre composites. The mechanical properties of the composites displayed an upward trend as the amount of fibre in the matrix was increased. Britto et al. [6] examined Alkaline Treatment on laminates to improve mechanical properties of Jute fibre-reinforced epoxy (LY556) composites. The morphological and mechanical characteristics were studied before and after the alkaline treatments. Awad et al. [7] examined the influence of date palm powder (DPP) on the mechanical and thermal characterizations of a high-density polyethylene (HDPE) matrix. TGA analyses showed improved stability when DPP is incorporated in HDPE. Ganeshan et al. [8] evaluated the mechanical properties of sisal and bamboo fibre reinforced polymer matrix composites. The results conclude that there is improvement in the mechanical properties as the amount of fibre is increased. As composition of fiber reaches a critical percentage, composites show lower tensile strength, impact strength, and flexural strength, this is due to disruption of transfer of load to the bonding fibres.

Chandrika et al. [9] fabricated natural fibre reinforced polymer matrix composites for electronic circuit board applications. The conventional compression moulding process was employed to produce madar fibre reinforced-epoxy composites with bio solid waste sugarcane bagasse ash fillers. Mbeche et al. [10] evaluated the mechanical properties of sisal/cattail hybrid reinforced polyester composites. The composites were fabricated using a simple hand layup method; the samples were prepared as per ASTM standards for the investigation of tensile, flexural and compressive strength. The study revealed that at a 20% weight fraction of fibre, optimal characteristics were found.

Mahesh et al. [11] compared the results from experimental and analytical study on E-glass and basalt fibre laminates; the mechanical properties of the composites were evaluated and the study demonstrated the basalt fibre is robust compared to commonly used glass fibres. Ramachandra Reddy et al. [12] evaluated the mechanical properties at various weight percentages of filler in epoxy composites. It was seen that the highest composition of epoxy resin and 10 wt.% of Betel nut fiber composite showed optimal characteristics.

From the literature, it is seen that a certain combination of natural fibres and synthetic fibres in the matrix result in significant improvement in the mechanical properties. The gap in research as observed from the literature review revealed that there is no direct comparison of natural and synthetic fibre reinforced composites when graphite is added as filler with varying percentages. Therefore, in the present context glass fibre (synthetic) and sisal fibre (natural) reinforced epoxy composites filled with 5, 10, 15 wt.% graphite were used to evaluate the tribo-mechanical properties.

MATERIALS AND METHODS

Materials

Fundamentally, a composite is made up of a fibre, matrix, additives and fillers. Desired properties of a composite is decided by the constituents; therefore, the selection of appropriate elements to be added to fabricate a composite is a decisive step.

Glass fibre

Glass fibres are synthetic fibres manufactured as bundles of filaments. The diameter of the filaments range from 1-20 μm and are used to improve the dimensional stability, impact resistance, flex modulus, creep resistance etc. of the composite. Since glass fibres are of an amorphous structure [13], the characteristics of glass fibres remain the same along the length and breadth, giving higher strength to the fibres.

E-glass fibres stand out from the rest because of their phenomenal tensile strength of 2400 MPa and 73 GPa Young's modulus [14]. E-glass fibres have low elastic moduli when compared to other fibre reinforcements. In addition, E-glass fibres are capable of higher resistance to creep and creep (stress) rupture. One of the main advantages of E-glass fibres is their higher performance to cost ratio.

Sisal fibres

Sisal fibre is a hard natural fibre extracted from the leaves of the sisal plant (Agave sisalana) [4]. The length of the fibres varies between 1.0-1.5 m and the diameter is about 100-300 μm. Sisal fibre is distinctively a hollow sub-fibre bundle. An individual bundle of fibres predominantly contains 87.25% water and only 3% of fibre can be extracted from the bundle, which contributes up to 1000 fibres from the leaf weight of 600 g.

Presence of ligno-cellulosic material [15] in the cell wall and reinforcement of helical micro fibrillary bands of cellulosin fibre provide longitudinal strength to the fibre. Lignocellulosic material belongs to the hydroxyl group; hence, it has a tendency to repel a hydrophobic matrix; therefore, these fibres are subjected to chemical treatment to improve the surface adhesion and bond strength between the fibre and the matrix.

Epoxy resin

Epoxy resins are hydrophilic resins and are compatible with a variety of reinforcing agents, fillers and fibres. Epoxy resins contain a hydroxyl molecule (–OH) [16] along their chains and most inorganic material surfaces, i.e. fibres, fillers, metals and ceramics have a positive polarity, which helps to create higher strength and more adhesive bonds. Surface energy is another concept that has to be discussed; if the surface energy of a fibre is lower than the epoxy, shrinkage will be higher, which affects the characterization of the composite [17]. The surface energy of the LY 556 epoxy resin was found to be similar to the selected fibres; hence, in this experiment LY 556 resin was chosen as the matrix

Graphite powder

Graphite is an allotropic form of carbon; according to studies it is evident that graphite possesses special adhesion and lubrication abilities of, giving the material a higher coefficient of friction, volumetric wear rate and friction stability. Besides this, the fact that graphite has "super lubricity" makes it [18-20] an efficient constituent in brake pad material.

Composite fabrication

The hand layup and bag moulding process were employed to fabricate the composite material with 5, 10 and 15 wt.% graphite. A square composite plate of 400 x 400 mm with a 3.2 mm thickness was fabricated using glass/sisal fibre and epoxy resin. The masses of glass-sisal fibre, epoxy resin and graphite were calculated as per their volume and density as shown in Table 1.

TABLE 1. **Density of components**

Component	E-glass	Sisal	Epoxy resin	Graphite powder
Density ρ [kg/m^3]	2.54	2.55	1.15	2.26

Furthermore, number of layers of the fibre strands to be used was decided based on the thickness of the laminate. The glass and sisal mat strands were marked and cut with the help of a marker and scissors to layer up the fibre mat until the desired thickness level was reached. Later, a pre-calculated mass of epoxy resin along with hardener was mixed with the graphite powder.

Firstly, a flat surface was cleaned, dried and gently etched for a protective layer to adhere to. A layer of resin coating was applied using a brush and done until the necessary thickness of the laminate is reached.

In the next step, vacuum was created to remove surplus resin and air trapped between the layers. A breather and perforated sheet were used to create uniform pressure around the system to allow air to escape from the composite. The various stages of the fabrication process are as shown in Figure 1.

Curing of the composites was carried out at 100°C for an hour. The post curing process was conducted in a hot air oven at 80°C for about 24 hours to confirm complete curing of the composite.


Weighing of different constituents of composite system

Flat surface

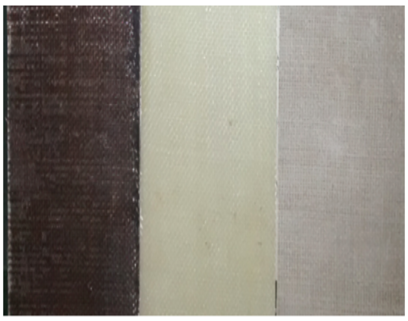
Covering glass fibre

Breather sheet

Composite system with polymer sheet

Vacuum bag

Post curing



Composite sheets

Abrasive water jet machine

Fig. 1. The various stages of the fabrication process

Characterization

In the present study, glass, sisal and glass-sisal hybrid fibre reinforced epoxy composites filled with different wt.% of graphite were tested to ascertain their mechanical and tribological properties, as per various ASTM standards.

Mechanical characterization

Figure 2 shows the different ASTM standards to examine the tensile, flexural, impact strength and hardness. The hardness of all the produced composites was determined by means of a Shore durometer to evaluate effect of reinforcement and hybridization.

Wear analysis and optimization

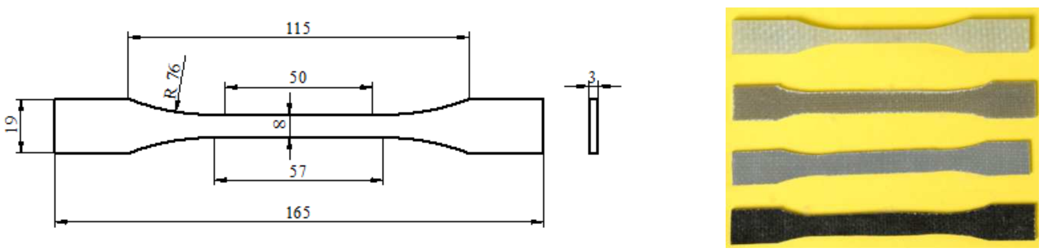
In the current study, the tribological characteristics of the developed composites were evaluated using a pin-on-disc tribometer (POD). The tests were conducted as per ASTM G 99-95 Standards. Taguchi optimization technique was employed to design experiments by controlling different parameters to obtain efficient results.

The tests were designed and conducted by varying different parameters such as the sliding velocities (2, 3 and 4 m/s), load (10 to 30 N), sliding distances (1, 2 and 3 km), and track diameter (120 mm). Furthermore, the weight losses were measured using an electronic balance with the accuracy of 10^{-4} grams.

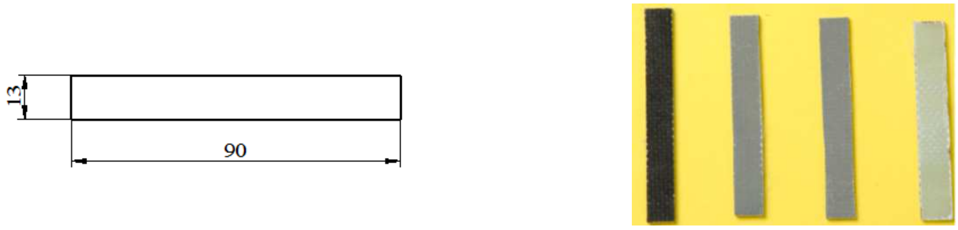
Optimization technique

The design of experiments (DOE) with the help of the L27 orthogonal array was chosen to optimize the wear parameters (Table 2) by considering the applied load, sliding velocity, percentage of filler reinforcement and sliding distance.

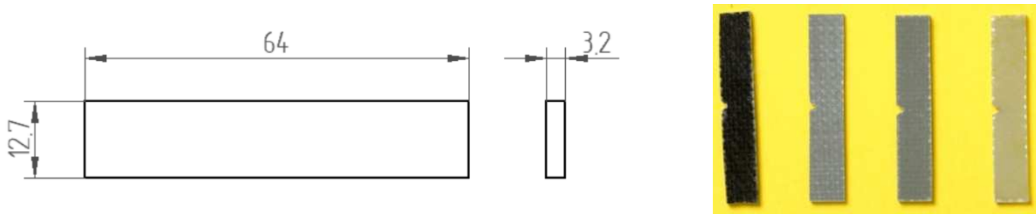
Fig. 3. ASTM G 99-95 standard wear test specimens



ASTM 790 Tensile test specimens



ASTM D790-03 Flexural test specimens



ASTM D 256 Impact test specimens

ASTM D2240 Hardness test specimens

Fig. 2. ASTM standard test specimens

TABLE 2. **Process parameters and their values for L_{27} array**

Level	wt.% of filler	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

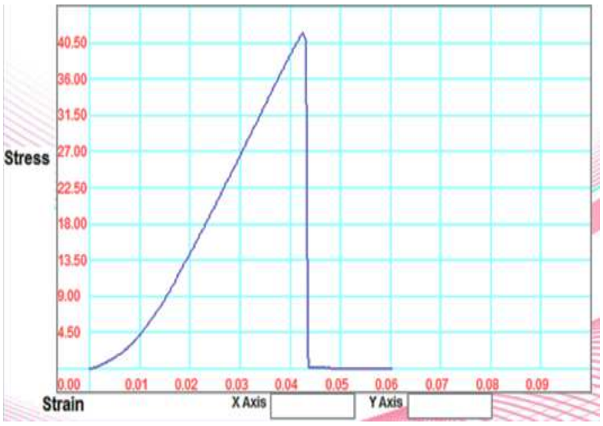
RESULTS AND DISCUSSION

Many researchers have tried to fabricate FRP composites by the hand layup technique without considering vacuum bagging and post curing; it is evident from the literature that the produced composites are prone to delamination and debonding and most of researchers focused their study only on synthetic fibres rather than natural fibres. Therefore, in this research work, natural fibre FRP composites were fabricated to evaluate the mechanical and tribological properties as per ASTM standards. Hence, vacuum bagging and post curing processes were additionally adopted in this research work to develop the composite plates.

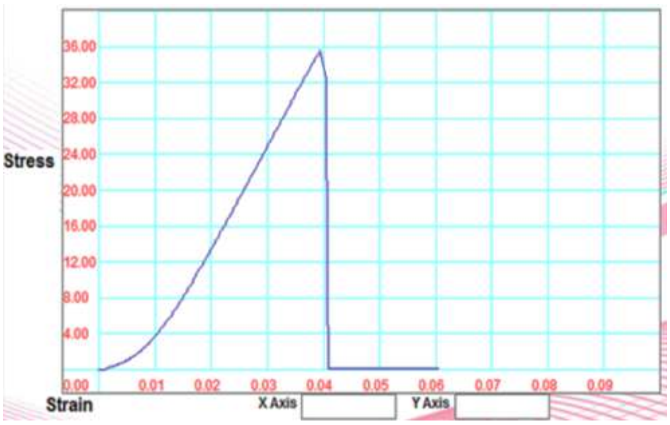
Tensile strength

ASTM 790 standard tensile tests were conducted to evaluate the strength of G the lass-epoxy, sisal-epoxy and glass/sisal-epoxy hybrid composites by varying the graphite filler in the amounts of 5, 10 and 15 wt.%. Figure 4 shows the stress-strain curve for the 10 wt.% graphite filled composites. It is evident that the tensile strength of the glass is greater compared to that of the sisal.

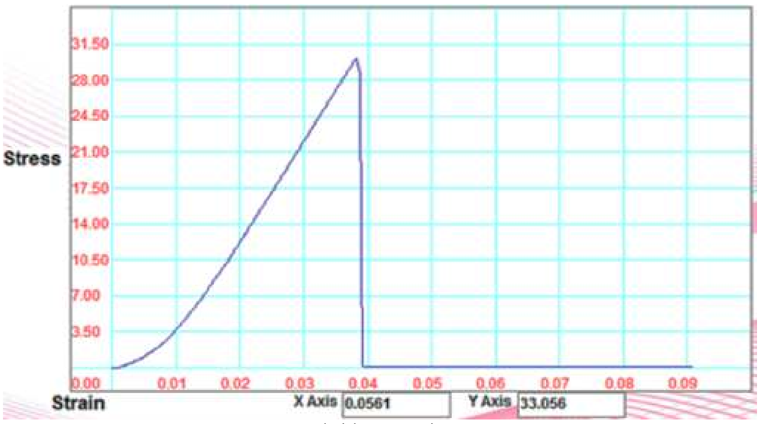
The stress-strain behaviour of the 10 wt.% graphite filled composites is shown in Figure 7. It was noticed that the stress linearly grows with an increase in load till the ultimate point. It was also observed that the 10 wt.% graphite filled glass FRP composites exhibit a higher tensile modulus of 1620 MPa having 4.25% elongation in comparison with the sisal and hybrid composites with a small change in the strain rate. It is evident that FRP composites generally exhibit nonlinear stress-strain behaviour, but developed composites show linear stress- strain behaviour. This behaviour is dictated by the uniform distribution of fillers in the composite (Fig. 5) and the chosen fabrication process.



Glass-epoxy composite

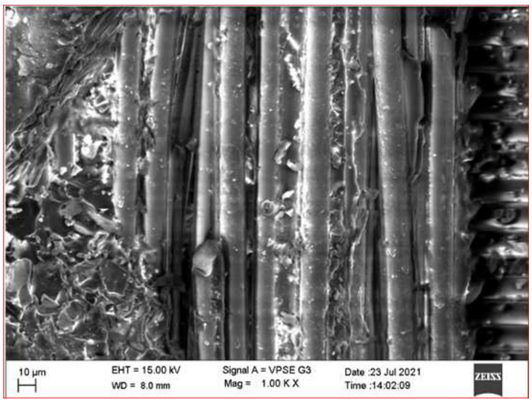


Sisal-epoxy composite

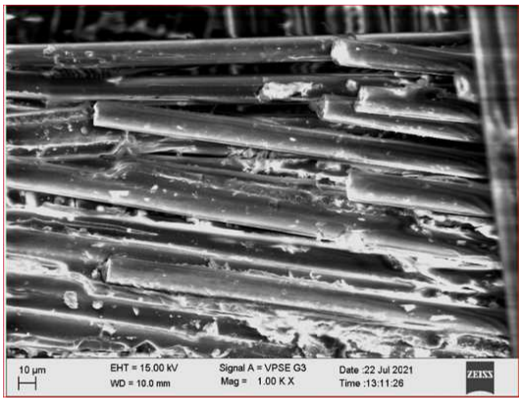


Hybrid composites

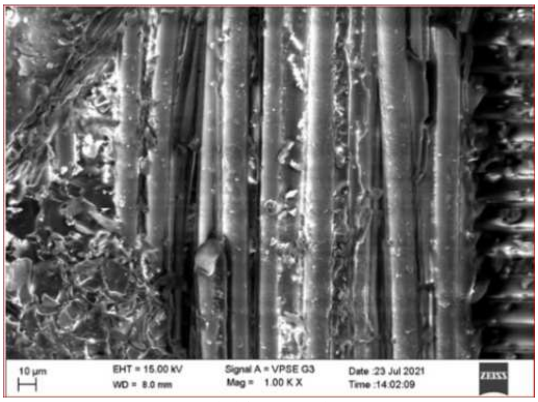
Fig. 4. Stress-strain curves for composites with 10 wt.% graphite



Glass-epoxy composite



Sisal-epoxy composite



Hybrid composite

Fig. 5. Microstructre of composites

After conducting the tensile test, SEM analysis was carried out to understand the morphology of the glass--sisal-epoxy composite system. It was observed that fibres are pulled out, which leads to fibre fracture in all the cases (Fig. 6).

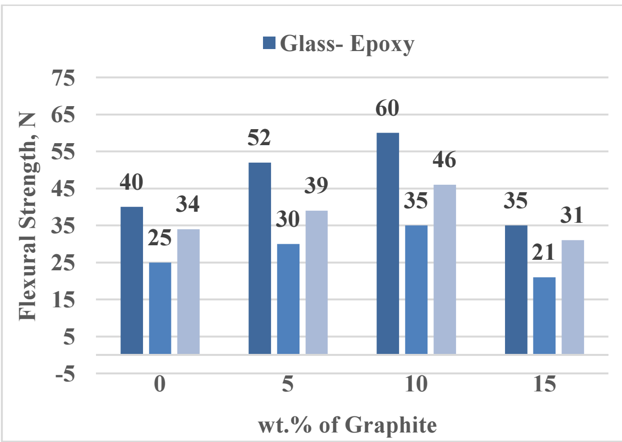


Fig. 6. Flexural strength of glass-epoxy, sisal-epoxy, sisal-glass-epoxy hybrid, wt.% graphite composite

Flexural strength

Flexural tests of the glass-sisal-epoxy composites with different wt.% of graphite were conducted as per the ASTM D790-03 standard to evaluate the effect of filler content and hybridization effect on the flexural properties.

Figure 6 presents the load carrying capacity of composites filled with different weight fractions of graphite. It was noticed that the load carrying capacity rises with an increase in the wt.% of graphite and the flexural strength is increased by 40, 50 and 35.2% for the sisal, glass and hybrid FRP composites, respectively with the addition of 10 wt.% graphite. Uniform distribution of the filler results in better adhesion between the fibre and matrix of A graphite addition beyond 10 wt.% results in brittleness, poor dispersion and the possibility of the presence of voids, which leads to the formation of weak bonding at the interface regions; hence, the flexural strength is reduced. It was also observed that, with the addition of 15 wt.% graphite, hybrid composites shown reduction of 8.82% and glass-epoxy, sisal--epoxy composites shown reduction of 16 and 13% respectively w.r.t Hybrid composites.

Impact strength and hardness

The impact strength and hardness of the composites were evaluated as per the ASTM D256 and ASTM D2240 standards, respectively. It is evident that the addition of filler enhances the impact strength and hardness. The increase in impact strength may be due to the hard and brittle characteristics of the graphite filler, the interfacial reaction between the matrix, filler and fibres, uniform dispersion of particles and effective barrier for pinning and separation of induced cracks.

Wear properties

Wear tests were conducted as per Section Wear analysis and optimization using the POD experimental setup as per DOE. MINITAB software was used to develop Taguchi, ANOVA and multiple regression analysis based on the results obtained from the POD experiments to establish the correlation between significant terms.

Figures 7 and 8 show the S/N ratio of sisal and glass fiber. From the figure it is observed, percentage of reinforcement i.e. graphite has a major influence on wear of the composite.

It was noticed that the reinforcement has a 57.99% influence and the sliding velocity has an 18.51% influence on the wear rate. It is observed that friction increases with an increase in the contact surface and load on the wear rate. Therefore, the reinforcement is a major influencing parameter to resist wear loss. Similarly, observations were made by conducting multiple linear regression analysis of the sisal FRP.

Furthermore, wear analysis of the glass and hybrid FRP composites were conducted using POD and DOE and it was found that graphite reinforcement has the highest influencing factor to resist wear loss. A comparison of glass, sisal, and hybrid FRP composites was conducted, and it was found that the sisal--graphite FRP system has higher wear loss compared to glass and hybrid composites, The fundamental feature of employing natural fiber (sisal) as reinforcement is that, produced composites are ecologically benign and biodegradable moreover, the use of graphite filler in natural composite improves mechanical and tribological properties.

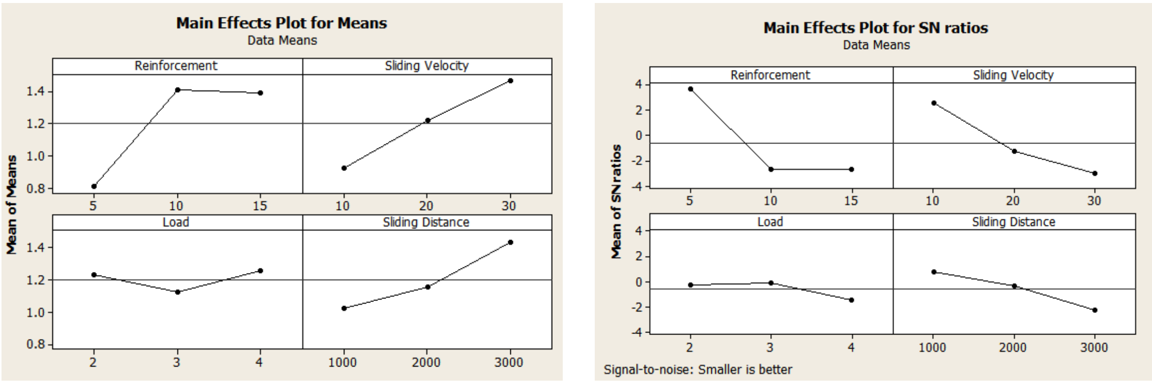


Fig. 7. Means of means and S/N ratio plot for glass fibre

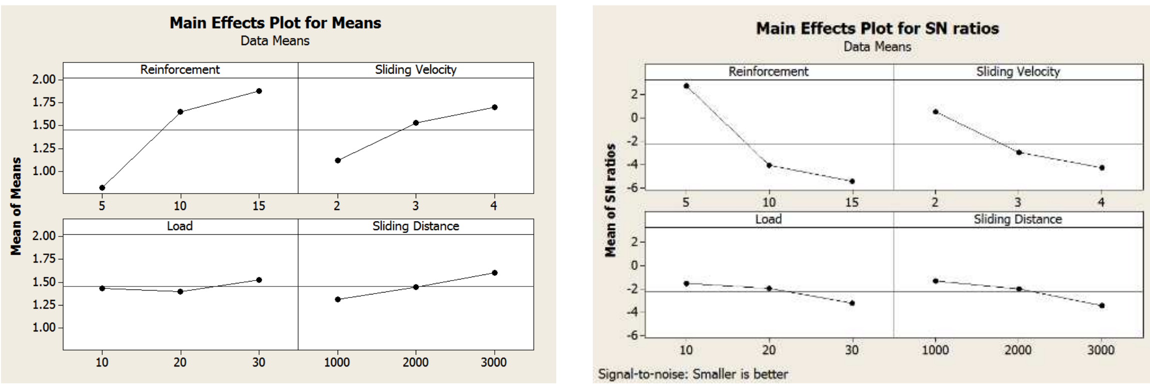


Fig. 8. Means of means and S/N ratio plot for sisal fibre

TABLE 3. **Analysis of variance results for S/N ratio for sisal fibre**

Source	DF	Seq SS	Adj SS	Adj MS	F	P [%]
Reinforcement	2	345.653	345.653	172.827	29.38	57.99
Sliding velocity	2	110.349	110.349	55.174	9.38	18.51
Load	2	13.48	13.48	6.74	1.15	2.26
Sliding distance	2	20.688	20.688	10.344	1.76	3.47
Error	18	105.871	105.871	5.882		17.76
Total	26	596.041				100

CONCLUSIONS

- Graphite filled sisal, glass and hybrid FRP composites were successfully synthesized by the hand layup method and the bag moulding process along with post curing.
- The addition of the graphite to the synthetic and natural FRP composites enhances the mechanical and tribological properties.
- The mechanical properties of the sisal FRP show lower tensile, flexural, impact strengths and hardness compared to the synthetic and hybrid composites due to the poor bond between sisal, graphite and epoxy.
- It was also observed that the 10 wt.% graphite filled glass FRP composites exhibit a higher tensile modulus (1620 MPa) than the sisal FRP composites (640 MPa) [8, 16].
- It was noticed that an increase in the wt.% of graphite in the sisal, glass and hybrid FRP composites increased the flexural strength by 40, 50 and 35.2%, respectively.
- Use of 50% sisal in place of glass, showed considerable improvement in the mechanical properties and wear resistance.
- It is evident that natural fibres are biodegradable and eco-friendly; therefore, sisal fibres can be used as an alternative to glass fibre in FRP composites.

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