IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 11, Issue 11, November 2024

DOI: 10.17148/IARJSET.2024.111116

Effect of Stacking Sequencing and Fiber Orientation on the Tribological Characteristic of Carbon/Glass/Jute Reinforced Epoxy Hybrid Composite

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Abstract: In the present investigation, an experimental analysis was conducted to evaluate the influence of the stacking arrangement and orientation on the tribological properties of epoxy hybrid composites reinforced with carbon, glass, and jute fibers. Additionally, a comparative analysis was performed with non-hybrid base composite materials to ascertain the potential impact of the above-mentioned variables. The hand lay-up technique was used to create the composite samples, which were cured for 72 hours at room temperature under mild pressure. All specimens were created with a total of 18 layers of plies using the matrix material LY556 epoxy resin and hardener HY951. A dry sliding wear test was performed utilizing an ASTM G99 Pin on Disc wear tester with the two operating parameters of a load of 20 and 150 N, a sliding velocity of 2 and 8 m/s, and a sliding distance of 1000 and 500 m. The non-hybrid composite sample J18 with 18 layers of jute fibre exhibited the most wear loss, whereas the hybrid samples with jute in the centre and carbon and glass fibre on the outside face showed the least wear loss. Two samples, S5 and J18, both with jute fibre in the top layer, failed the wear test owing to shear failure. Since the jute fibre's adhesion to the matrix is low, placing it in the middle of the composite can improve the hybrid material's tribological characteristics. The outcome shows that changing the stacking sequence has a greater impact on tribological properties than fibre orientation.

Keywords: Tribological Properties; Pin on Disc; Stacking Sequencing; Fiber Orientation; Carbon Fiber; Glass Fiber; Jute Fiber.

I. INTRODUCTION

Composite materials are important in a variety of applications. Many sectors were charmed by their adaptability to various settings and advantageous features. Because of their exceptional properties, carbon and glass fibre-reinforced epoxy composites are employed in the aerospace and automotive industries. Because epoxy resins are brittle, reactive liquid rubbers and inorganic additives can be used to increase their toughness. Composite materials are being substituted for conventional materials due to their superior characteristics, including exceptional strength-to-weight ratio, elevated tensile strength, and low thermal expansion rate. [1]. New material innovations are underway and are progressing at a rapid pace. Many industries adopted composite materials because their low cost, simple availability, lightweight, and excellent specific characteristics all contribute to their success [2]. Combinations of two or more materials having a distinct character that don't dissolve or mix together are known as composite materials [3]. The different materials in the composite work together to give unique composite properties. The initial stage is referred to as the reinforcing phase, while the subsequent stage where it becomes firmly established is known as the matrix. The reinforcing phase material might be fibres, elements, or flakes. In general, matrix phase materials are continuous [4]. Concrete reinforced with steel and epoxy reinforced with graphite fibres are two examples of composite structures. The phrase hybrid composites are increasingly gaining critical relevance in terms of economic and ecological compatibility. These are materials made up of two or more separate natural and synthetic fibres that have been reinforced with suitable polymer matrices to create a composite material with properties similar to manufactured materials [5]. Furthermore, to keep up with current technological developments, it has become vital to develop materials that are less hazardous to nature to safeguard our environment for many more years. This idea has driven people to use hybrid composite materials in daily applications.

The favourable properties of these composites, such as affordability, recyclability, and biodegradability, have also made them a feasible option for synthetic materials, which may be used in a range of applications [6]. Mechanical and thermal properties of the glass and jute fibre-impregnated epoxy composite were predicted. The goal was to improve mechanical properties by combining jute and glass fibres together [7]. Cellulosic fibres like jute, cotton, broom, sisal, flax, and hemp have recently been used to strengthen polymers. The matrix options are limited and require a low melting temperature polymer to provide a processing window typically between 200 and 220^{0}C [8]. Wheat straw, rice husk, pine bark, coir, and plant gum-rosin were used as natural fillers to improve mechanical properties at a low cost [9]. Epoxy resin is a high-performance polymer that is used in a variety of industrial applications because of its high bending strength, excellent adhesion, minimum shrinkage, exceptional electrical insulation, and resistance to chemical and solvent degradation [10].

Industrial significance may be found in the research of synthetic and natural fibres with epoxy matrix materials and their processing methods for generating composites with higher strength and hardness [11]. The main drawback of natural fibre is its poor compatibility with polymer matrixes for adhesion. Natural fibber’s future potential when combined with synthetic fibre is to boost its strength [12]. Furthermore, the mechanical and tribological properties of jute fiber-reinforced epoxy composites were improved through chemical modification of the jute fibers, resulting in increased fiber-matrix adhesion and water absorption resistance [13]. To boost mechanical strength, it is necessary to add hydrophobicity through chemical treatment, which improves natural fibre performance by filling the compatibility gap between hydrophilic fibres [14]. The tribological properties of carbon/glass/jute epoxy composites in terms of wear and tear have been investigated in several studies. One study found that carbon fiber composite materials achieve superior wear resistance when molded horizontally to the direction of tribological wear, making them suitable for advanced bushing applications [15]. Mechanical and tribological properties enhancements are mostly dependent on characteristics such as interfacial adhesion, orientation, distribution of matrix-fibres [16]. The filler loading and operating conditions have a considerable impact on composite wear [17]. Another study showed that the addition of rubber crumb as a filler in jute-epoxy-rubber crumb hybrid composites enhances their resistance to abrasion [18]. Hard particulate fillers made of metal or ceramic particles, as well as natural filler materials, are being employed to significantly increase wear resistance [19]. The adhesive wear is directly proportional to the applied load and the sliding distance, and indirectly to the metal's hardness [20]. Zongrong Yang et al. [21] investigate the effects of MoS_2 microencapsulation on a composite material's tribological characteristics under water lubrication conditions.

The researchers discovered that composites with MoS_2 microcapsules exhibit better tribological characteristics than composites without MoS_2 content. The composites comprising the MoS_2 microcapsules had decreased sliding friction and a smoother surface morphology due to the protection provided by the microcapsule walls. Levente Ferenc Toth et al. [22] released a paper on the tribological characterization of environmental jute, and friendly basalt fibre reinforced thermoset composites. The experimental result proved that tri-bio composites filled with MoS_2 have the maximum coefficient of friction, whereas composites mixed with PTFE have the least coefficient of friction and also have the longest service lifespan. S Joseph Irudaya Raja et al. [23] conducted an experimental examination of the wear characteristics and microstructure behaviour of composite materials made of areca nut fibre. The experimental data demonstrates that the wear rate varies with the normal load application value and that weight loss typically increases with an increase in the normal load applied; these two quantities are directly proportional to each other. Z. Edward Kennedy et al. [24] investigate the influence of hybridization and stacking order on the mechanical and tribological characteristics of composites made of glass and jute fibres.

According to the results of the erosion test, the hybrid composite with the glass top exhibits more erosion resistance than the non-hybrid glass fibre polymer matrix composite. Pranjal Borah et al. [25] published a paper based on the wear characteristics of glass/jute hybrid epoxy composites with different types of added fillers. The findings demonstrate that, compared to SiC and fish scale-filled composites, the composite with the sawdust filling exhibits the least wear loss at lower loads as well as higher loads and at a higher velocity. M Venkatesan et al. [26] The wear properties of glass fibre and CNT-reinforced hybrid polymer composites were investigated experimentally in this work. The result shows the wear rate of glass fibre-reinforced polymer composites lowers as the volume percentage of CNTs increases. The outcome also makes it quite evident that, when the CNT proportion rises, the coefficient of friction also rises. K Sabeel Ahmed et al. [27] presented a report on the wear properties of jute/epoxy composites using SiC/Al_2O_3 filler material. The results show that adding fillers boosts the wear resistance of the jute/epoxy composite substantially. Furthermore, Al_2O_3-filled composites are more resistant to wear than SiC-filled composites.

Hamza Abdulrasool Al-Tameemi et al. [28] investigated the Wear resistance behavior of composite materials reinforced with woven glass fibers has been examined in different setups. The study found that wear resistance can be influenced more by toughness rather than hardness.

Interestingly, as the sliding speed increases, the wear rate of the composite with woven fibers rises, whereas the wear rate of the composite with chopped glass fibers stays constant. P Rajasekhar et al [29] investigate the tribological performance of hybrid composites made of polyamide and packed with short jute fibres and nano ZnO particles. The result reveals that the friction coefficient and wear rate of the hybrid composites were much lower than those of the non-hybrid pure polyamide composite.

Margabandu Sathiyamoorthy [30] In this study, the various stacking sequences were changed to experimentally examine the mechanical, thermal, and water absorption properties of hybrid composites reinforced with jute and carbon fibres. Zhengjie_Li et al. [31] examined the relationship between the wear and friction characteristics of glass fibre-reinforced epoxy resin composites and the size of the polytetrafluoroethylene (PTFE) particle. Results demonstrate that there is minimal variation in the friction coefficients of the four PTFE-filled epoxy resin composites and compared to epoxy composites filled with PTFE particles of the other size, the wear rate of the large size epoxy composite filled with PTFE particles is orders of magnitude lower. H. Jagadeesh et al. [32] investigated the presence of nanographene filler affected the abrasive wear and sliding characteristics of epoxy composites reinforced with bidirectional carbon fibre. The outcome demonstrates how the particular wear rate and coefficient of friction changed significantly throughout the running duration before stabilising at the steady state area.

Additionally, it is noted that the wear qualities are influenced by the fibre-matrix bonding characteristics and that the particular wear rate reduces as the load increases. Lihe Mao et al [33] examined the friction and wear properties of carbon fibre/epoxy stitched composites. They found that carbon fibre has good self-lubrication properties that’s why it also has low wear and friction coefficient. Oluwatosin A. Balogun et al [34] investigated the mechanical and wear properties of jute/tetracarpidium conophorum reinforced polypropylene composite for automobile interior application. They observed that the hardness and wear properties can be improved by blending filler materials at a lower weight percent revealing better performance which makes them fit for the development of automobile interior materials and mirror casing.

Aswani Kumar Bandaru et al [35] investigated the effects of hybridization on the interlaminar shear and abrasive wear parameters of composites made from polytetrafluoroethylene (PTFE) coated glass fabrics. They found that the hybridization and fibre design significantly enhanced the abrasive wear response of Glass/PTFE composites. Yanjun Xie et al [36] published a review article on Silane coupling agents used for natural fibre/polymer composites. The overall outcome shows that the silane surface treatment of fibre increases the interfacial adhesion of fibre and matrix. Overall, the research conducted in these studies emphasizes the considerable promise exhibited by carbon/glass/jute epoxy composites in various industries where there is a need for heightened wear resistance and superior tribological characteristics. These findings underscore the importance of exploring the potential applications of such composite materials in diverse fields to capitalize on their beneficial properties.

II. MATERIALS AND METHOD

2.1 *Materials*

In this current work, unidirectional carbon (230 GSM), glass (430 GSM), and bidirectional jute fibres (250 GSM) were used as reinforcement and Epoxy LY556, and hardener HY 951 were used as a matrix material to produce composites. The carbon fibre offers an excellent strength-to-weight ratio, a low thermal expansion, and great wear resistance. The Glass fibre exhibits low density, greater impact resistance, non-flammability, heat resistance, and effective electrical insulating qualities. The Jute fibre also has some distinctive qualities, such as low thermal conductivity, high tenacity, and bulkiness, however because of its poor strength-to-weight ratio, its qualities can be improved through hybridization with glass and carbon fibre.

2.2 *Preparation of the composites*

To create fifteen hybrid composite samples, the bidirectional jute mat and the unidirectional glass and carbon fibre were cut into 160 mm×120 mm. The hand lay-up technique was used to fabricate the composite. The hand lay-up approach was chosen above the alternatives mostly because it is the most popular, least expensive open moulding technique and requires the least amount of equipment, which is why many researchers have utilized it. The mould removal wax was used for quick and easy removal of the composite samples. After being removed from the mould, the samples were left to cure for 72 hours at ambient temperature and minimal pressure.

Fig 3.2. Fabrication Process [37].

Table 3.2 Shows the composition of materials which was used for the fabrication [37].

S.No	Sample Code	Weight of Carbon Fiber	Weight of Glass Fiber	Weight of Jute Fiber	Weight of Epoxy+ Hardener	Total Weight	Wt. % of Epoxy
1	S_1	26.70 g	53.20 g	29.00 g	135.40 g	244.30 g	55.42
2	S_2	27.10 g	52.90 g	29.20 g	135.50 g	244.70 g	55.37
3	S_3	27.00 g	53.00 g	28.30 g	136.90 g	245.20 g	55.83
4	S_4	26.10 g	53.50 g	28.80 g	136.80 g	245.20 g	55.79
5	S_5	26.00 g	53.80 g	28.70 g	142.20 g	250.70 g	56.72
6	S_6	26.20 g	53.10 g	28.70 g	141.30 g	249.30 g	56.67
7	S_7	25.40 g	52.40 g	28.00 g	138.60 g	244.40 g	56.71
8	S_8	25.70 g	51.20 g	29.60 g	137.90 g	244.40 g	56.42
9	S_9	25.90 g	51.40 g	28.70 g	137.70 g	243.70 g	56.50
10	S_{10}	26.60 g	51.50 g	28.90 g	136.50 g	243.50 g	56.05
11	S_{11}	26.00 g	53.20 g	28.20 g	139.10 g	246.50 g	56.43
12	S_{12}	25.50 g	52.60 g	28.00 g	138.90 g	245.00 g	56.69
13	G_{18}		157.80 g		96.70 g	254.50 g	37.99
14	J_{18}			86.70 g	173.60 g	260.30 g	66.69
15	C_{18}	79.50 g			53.00 g	132.50 g	40.00

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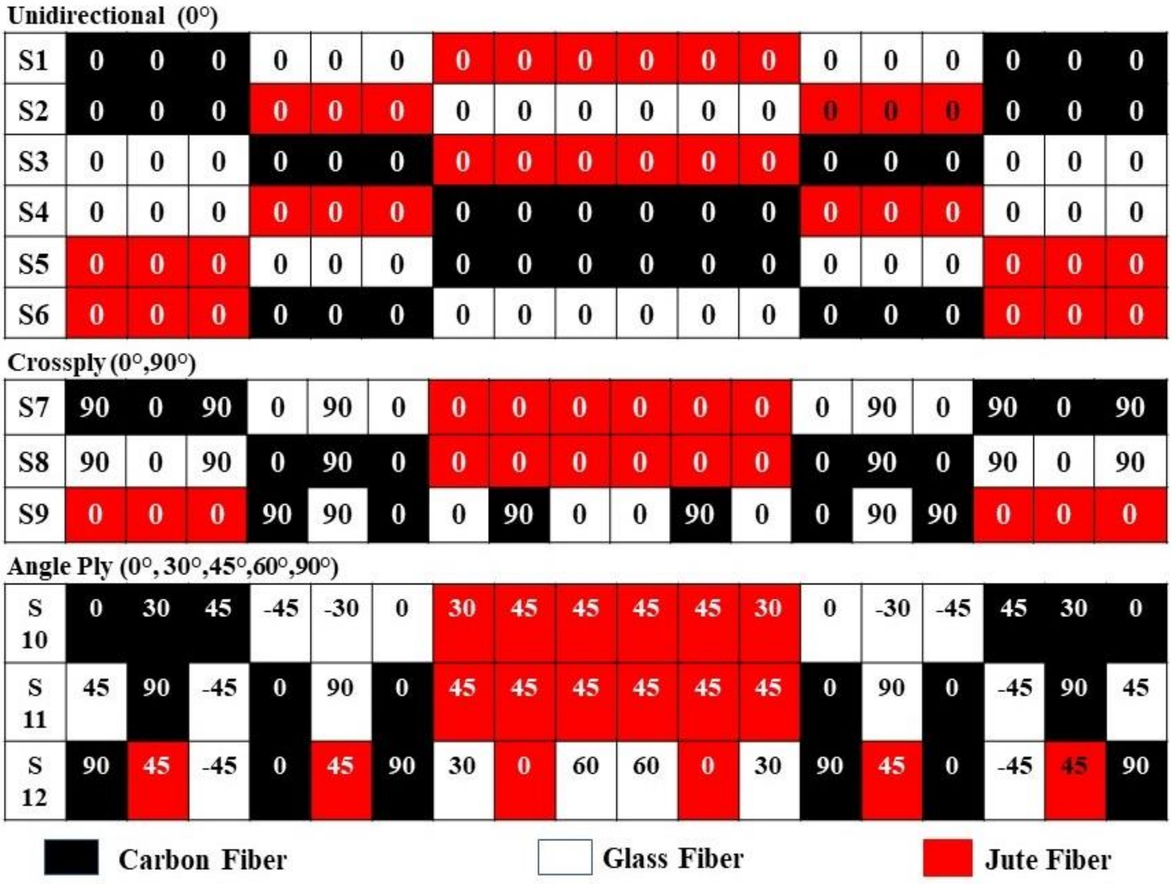

Unidirectional (0°)

S1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Crossply (0°,90°)

S7	90	0	90	0	90	0	0	0	0	0	0	0	0	90	0	90	0	90
S8	90	0	90	0	90	0	0	0	0	0	0	0	0	90	0	90	0	90
S9	0	0	0	90	90	0	0	90	0	0	90	0	0	90	90	0	0	0

Angle Ply (0°, 30°,45°,60°,90°)

S 10	0	30	45	-45	-30	0	30	45	45	45	45	30	0	-30	-45	45	30	0
S 11	45	90	-45	0	90	0	45	45	45	45	45	45	0	90	0	-45	90	45
S 12	90	45	-45	0	45	90	30	0	60	60	0	30	90	45	0	-45	45	90

■ Carbon Fiber ☐ Glass Fiber 🟥 Jute Fiber

Fig 3.3. Composites with various stacking sequences and fibre orientations [37].

2.3 *Tribological testing of fabricated samples*

A tribological test is a method employed for assessing the tribological characteristics of a material or system, such as friction, wear, and lubrication. These tests are utilized to gauge the effectiveness of a diverse array of materials like metals, composites, ceramics, and polymers. Furthermore, they can be applied to assess the efficacy of various lubricants, coatings, and surface treatments. Pin-on-disc, ball-on-disc, and block-on-ring tests are among the common types of tribological tests used to replicate real-world conditions. These tests are crucial for evaluating the tribological properties of materials and systems to enhance their performance, longevity, and dependability.

The pin-on-disc wear test was conducted following the guidelines of ASTM G99 standard. A Polycrystalline diamond hole saw drill bit was utilized to create a 9.5 mm diameter test specimen from the composite sheet. The wear tester disc consists of bearing hardness steel 58-60 BHN, exhibiting a surface roughness ranging from 1 to 1.2 µm.

The specimen was secured by a specifically designed holder and placed in contact with a rotating counter surface disc. The sliding wear assessment involved a wear track diameter of 140 mm, loads of 10 N and 150 N, sliding velocities of 2 m/s and 8 m/s, and fixed sliding distances of 1000 m and 1500 m respectively. The weight of the test sample was measured both before and after the test using a digital weighing scale.

Fig 3.4. Pin-on-disc wear tester.

III. RESULTS AND DISCUSSIONS

This research focuses on the tribological properties of bidirectional jute fiber and unidirectional glass/carbon fiber reinforced epoxy hybrid composite. When considering tribological properties, the stacking sequence plays a crucial role in determining surface attributes like roughness, hardness, and the propensity for wear and friction. Variations in sequences may result in the exposure of different fiber types to the contacting surface, thereby impacting the wear performance. Specific sequences could improve the load-bearing capacity, consequently reducing localized wear, whereas others might cause uneven wear due to distinct properties in various orientations. The alignment of fibers within a composite laminate is of utmost importance in determining its mechanical and tribological characteristics.

In accordance with the ASTM G99 standard, a tribological evaluation was conducted utilizing a pin-on-disc wear testing apparatus. A total of fifteen tests were carried out under identical testing conditions and ambient surroundings. The sliding test was executed with the fibers oriented normally to the sliding direction of the disc. The sliding wear assessment was performed with two distinct parameters as detailed below:

Table 4.1 Shows sliding wear test parameters.

Parameters	Applied Load	Sliding Velocity	Sliding Distance	Sliding Time
P1	20 N	2 m/s	1000 m	510 Sec
P2	150 N	8 m/s	1500 m	190 Sec

3.1 Wear in the Hybrid Composite Samples

Wear loss refers to the amount of material removed from a surface due to wear. Wear rate is the speed at which the wear loss occurs, typically measured in units of volume or mass of material removed per unit of time per unit of surface area. Both wear loss and wear rate can be influenced by factors such as the types of materials involved, the nature of wear, the pressure on the system, and the surrounding conditions where the wear is taking place. The process of wear occurs when one material surface moves against another material, and it is a complex phenomenon that occurs when two surfaces come into contact. As time progresses, the material is gradually eroded from the surface of the rubbing or sliding object.

3.1.1 Effect of Stacking Sequencing of Hybrid Composite on the Wear

Figures 3.1 (a) and 3.1 (b) show the graph between the wear & time of the hybrid composite by changing the stacking sequences according to the wear testing parameters P1 and P2, respectively. After analysing Figure 4.1(a), it was seen that specimen S1, with carbon fibre at the face material, shows minimum wear of 4.391 microns and the maximum wear seen in S5 specimen about 55.386 microns at 20N applied load, 2 m/s sliding speed, and 1000 m sliding condition.

However, in Figure 3.1 (b), the minimum wear was observed in the S3 specimen at about 74.610 microns. The maximum wear was seen in the S5 & S6 specimens at 150 N applied load, 8 m/s sliding velocity, and 1500 sliding distance. The Specimen S5, which has jute fibre in the upper layer, was broken after 92 sec due to shear failure during the wear test. The main reason for the shear failure of specimen S5 was to test it at a high applied load of 150N and the poor adhesive capacity of jute fibre with the matrix materials. The specimens S1 and S2, which have carbon fibre at a surface, also show better wear resistance at both testing parameters.

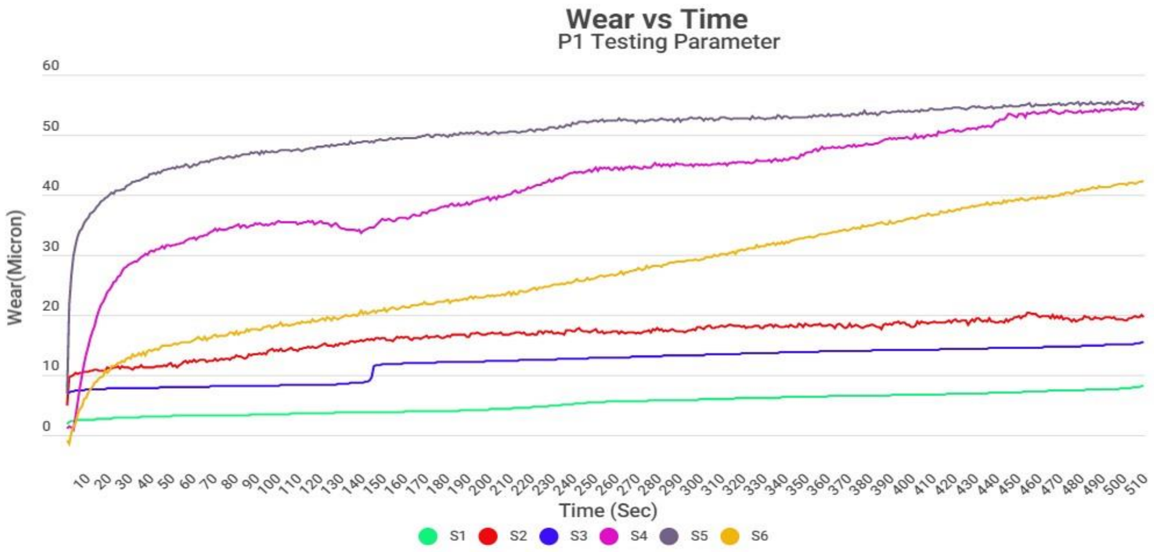

Fig 4.1 (a) Wear vs. Time graph of the hybrid composite by changing the stacking sequences at testing parameter P1.

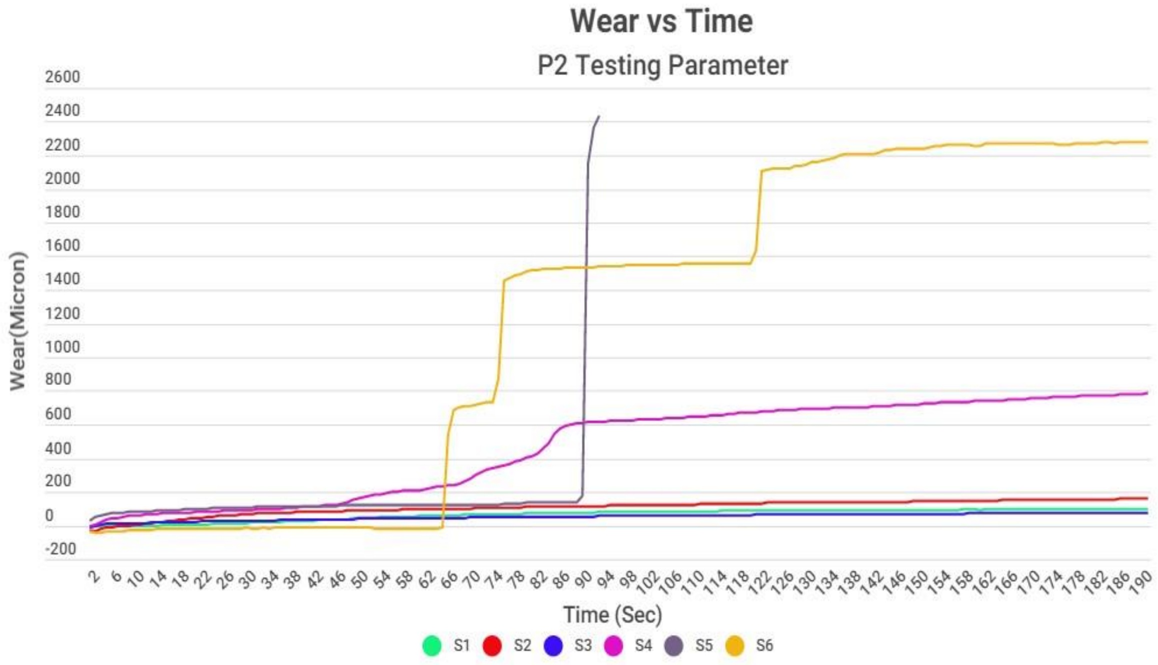

Fig 4.1 (b) Wear vs. Time graph of the hybrid composite by changing the stacking sequences at testing parameter P2 [37].

3.1.2 Effect of Fiber Orientation of Hybrid Composite on the Wear

Figures 3.2 (a) and (b) show the wear and time graphs of the hybrid composite when the fibre orientation is altered, based on the wear testing parameters P1 and P2, respectively.

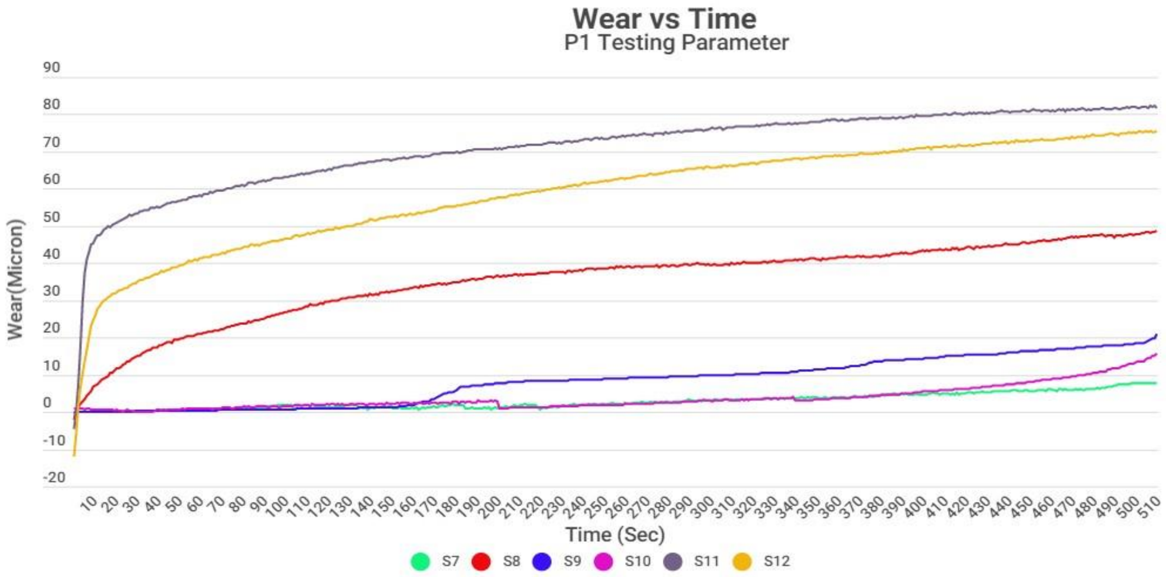

Fig 4.2 (a) Wear vs. Time graph of the hybrid composite by changing the fibre orientation at testing parameter P1.

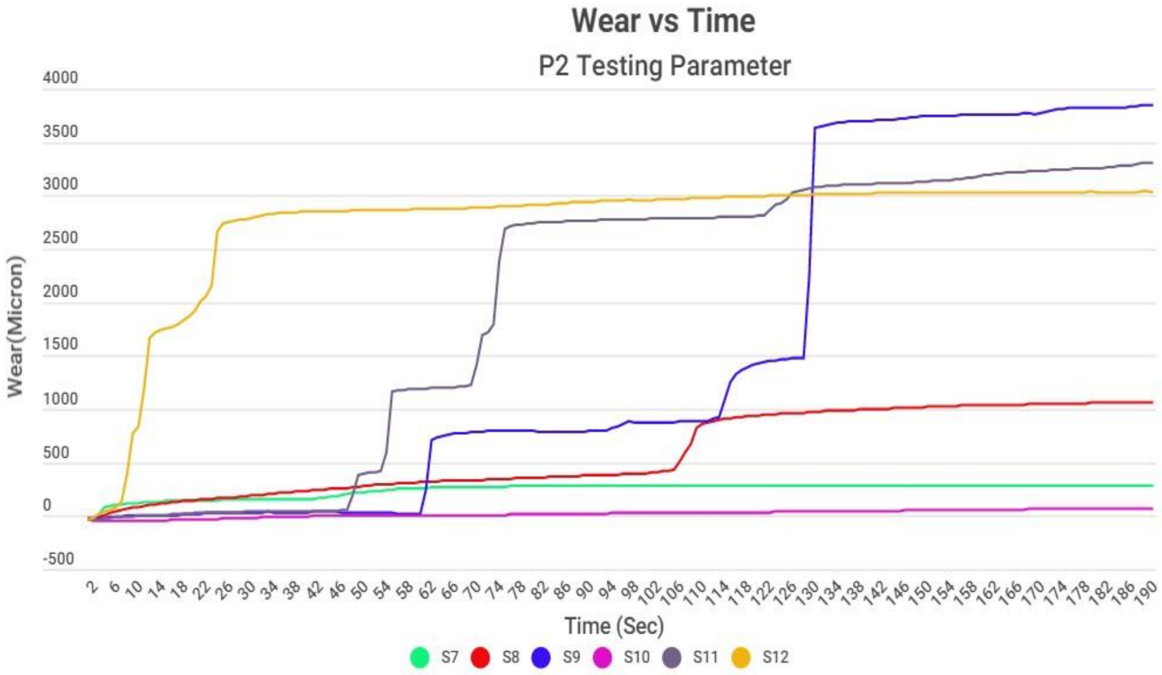

Fig 4.2 (b) Wear vs. Time graph of the hybrid composite by changing the fibre orientation at testing parameter P2.

Figure 3.2 (a) shows that specimen S7 with three-layer carbon fibre at (90^0, 0^0, and 90^0) fibre orientation has shown minimum wear of 7.759 microns, and maximum wear was seen at S12 specimens of about 75.643 microns. The S10 specimen, on the other hand, showed the least wear in Figure 3.2 (b), at about 65.991 microns. In comparison, the S9 specimen had the maximum wear recorded at about 3847.692 microns.

3.2 Wear in Non-hybrid Composite Samples

Figures 4.3 (a) and (b) depict the wear and time graphs of the non-hybrid composite based on the wear testing parameters P1 and P2. In both figures, the G18 samples had minimal wear of 16.251 and 440.498 microns, respectively, whereas the J18 specimen had maximum wear in both testing circumstances.

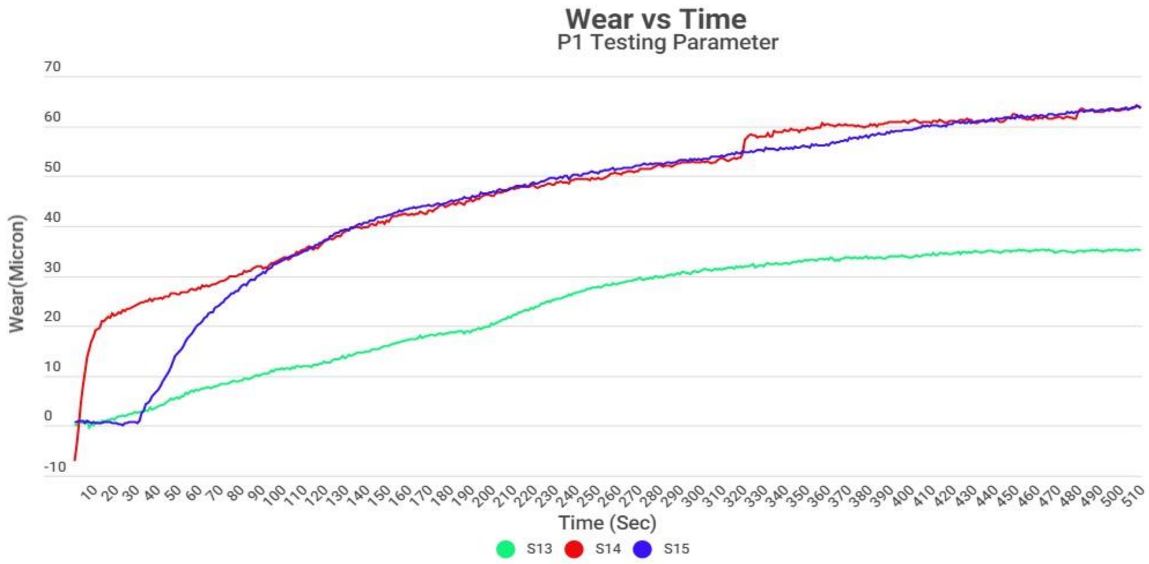

Fig 4.3 (a) Wear vs. Time graph of the non-hybrid composite at testing parameter P1.

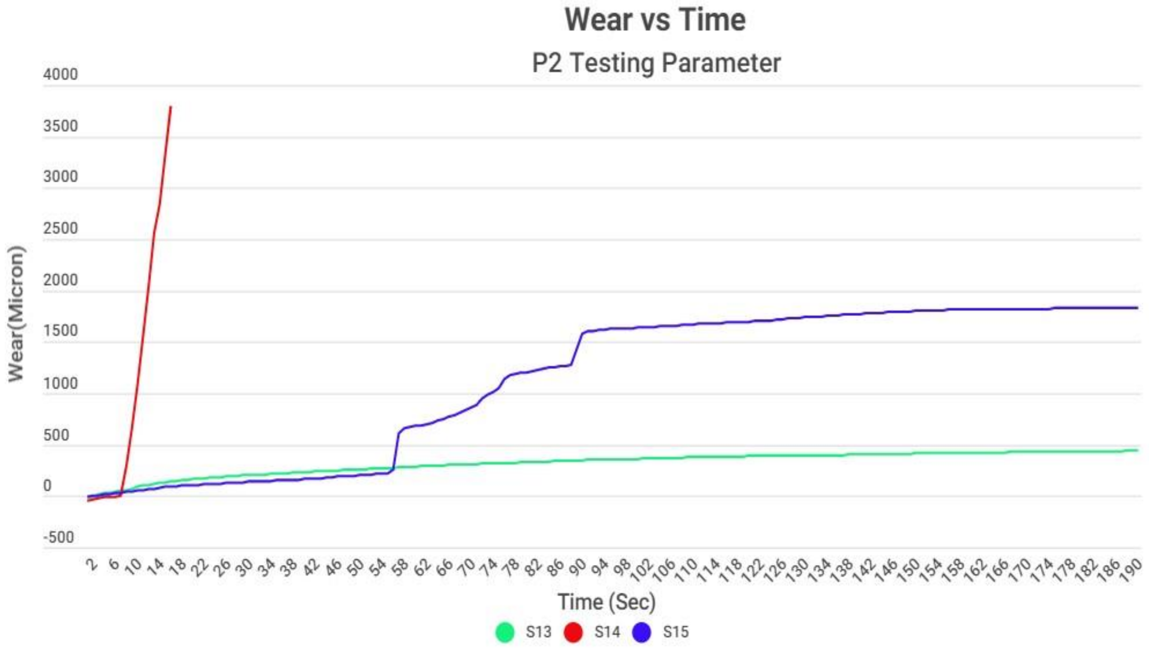

Fig 4.3 (b) Wear vs. Time graph of the non-hybrid composite at testing parameter P2 [37].

After evaluating the output data for both testing parameters, the least wear was seen in the S3 samples, and the maximum wear was noticed in the J18 samples. The wear resistance characteristics of the S1, S2, and S10 samples are also improved.

However, during the P2 wear testing parameter, two samples, S5 and J18, broke due to shear failure. S5 failed after 92 seconds, and J18 failed after just 16 seconds.

3.3 Coefficient of Friction (COF) of the Hybrid Composite Samples

3.3.1 Effect of Stacking Sequencing on the Coefficient of Friction

The coefficient of friction is a dimensionless value that represents the amount of resistance to motion between two surfaces in contact. It is often indicated by the Greek letter "mu" (μ). It is used to determine the amount of force necessary to accelerate an item that is at rest or to keep it moving at a constant pace. The coefficient of friction depends on the properties of the two surfaces in contact, such as their roughness, texture, and material. The coefficient of friction can range from 0 (for perfectly smooth surfaces) to 1 (for surfaces that are effectively welded together). Figure 4.4 (a) and (b) show the graph between the Coefficient of friction & time of the hybrid composite by changing the stacking sequences according to the wear testing parameters P1 and P2, respectively. The minimum COF observed in the S1 specimen in Figure 4.4(a) and the maximum COF seen in the S6 sample.

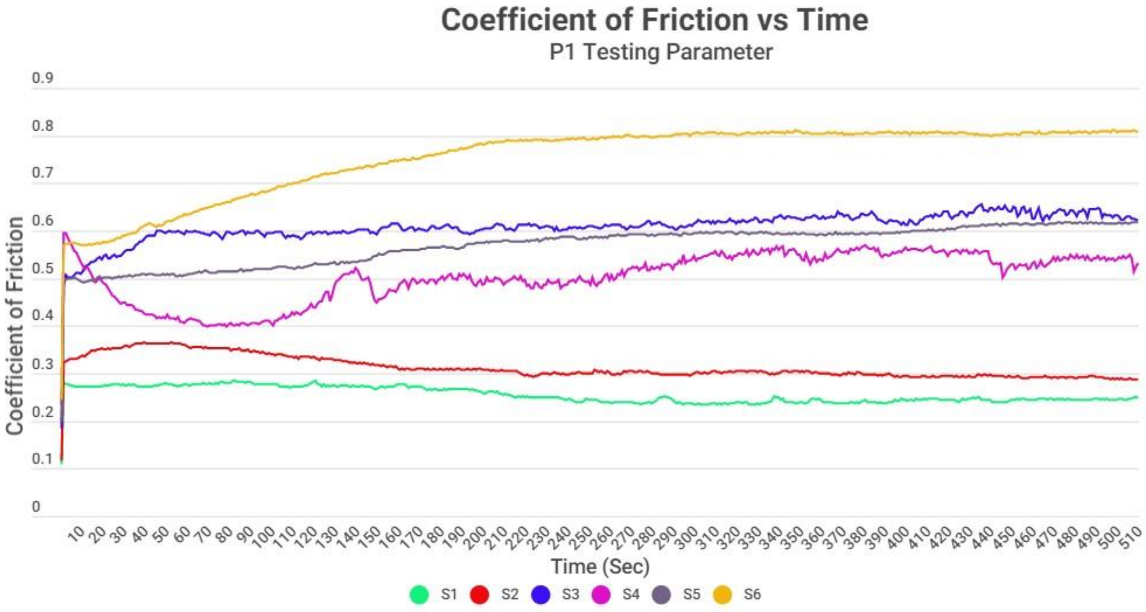

Fig 4.4 (a) Coefficient of friction vs. Time graph of the hybrid composite by changing the stacking sequence at testing parameter P1.

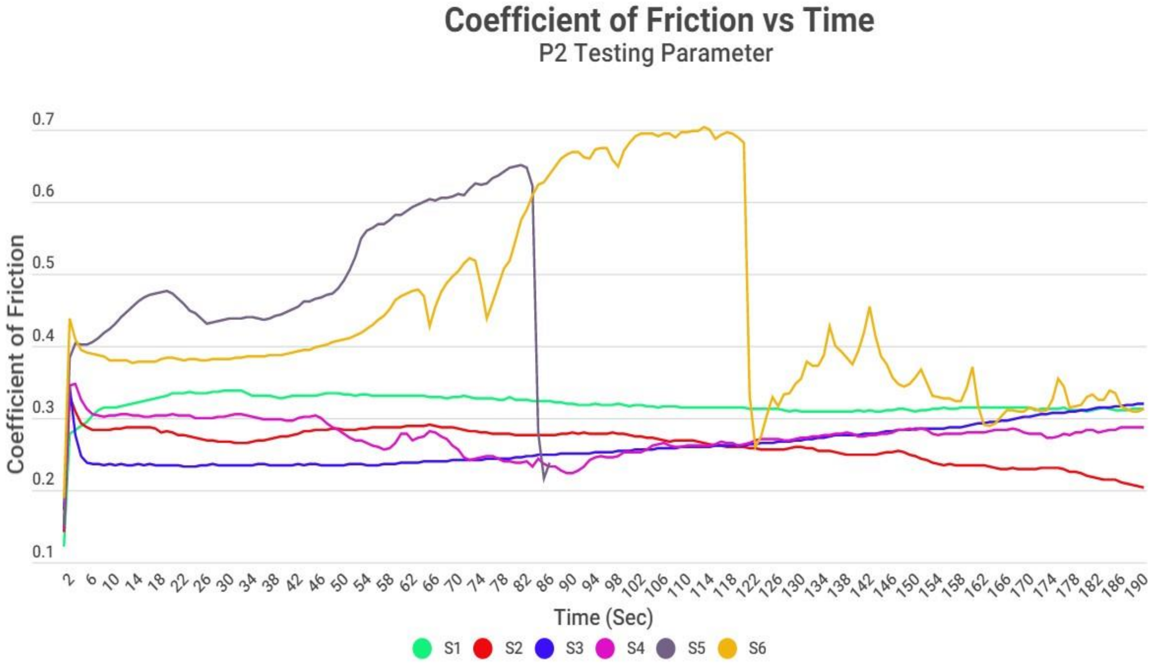

Fig 4.4 (b) Coefficient of friction vs. Time graph of the hybrid composite by changing the stacking sequence at testing parameter P2 [37].

In Figure 3.4(b), the minimum COF is observed in the S2 specimen and the maximum COF has seen in the S5 specimen and, the S1, S3, and S4 samples also have moderate values.

3.3.2 Effect of fibre orientation on the coefficient of friction

Figures 3.5 (a) and (b) illustrate the graphical representation of the relationship between the Coefficient of friction and time for the hybrid composite as the fibre orientation is varied based on the wear testing parameters P1 and P2, respectively. The S7 specimen displayed the lowest COF in Figure 3.5(a), while the S9 sample exhibited the highest COF. Conversely, in Figure 3.5(b), the COF values exhibited significant fluctuations over time; specifically, samples S7, S8, and S10 demonstrated minimal COF values, whereas the S9 samples showcased the highest COF value among the tested specimens. These findings underscore the dynamic nature of COF behavior in hybrid composites under varying fibre orientations and wear testing conditions.

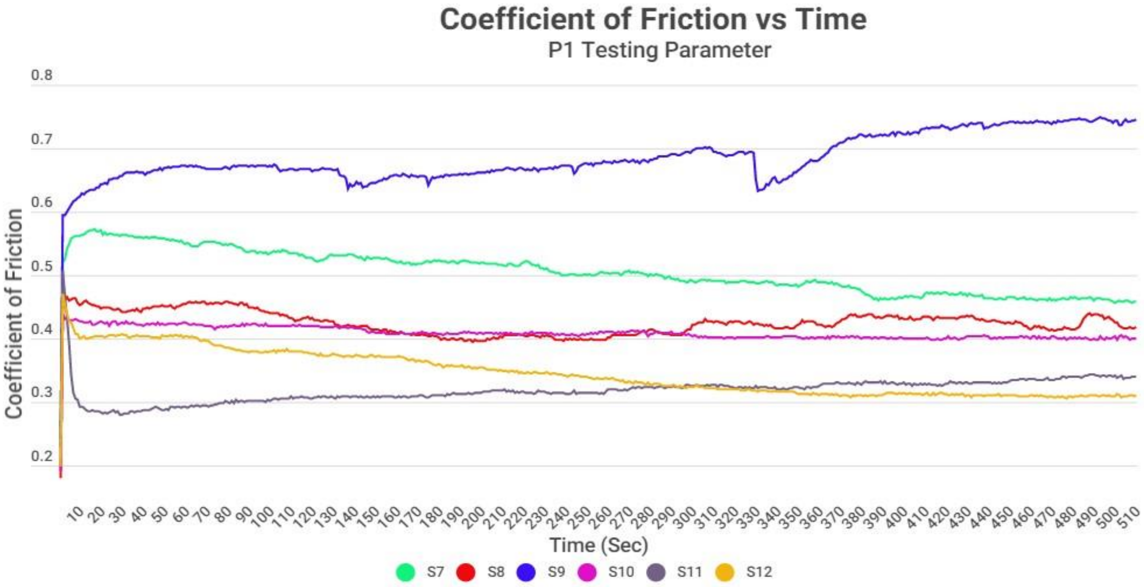

Fig 4.5 (a) Coefficient of friction vs. Time graph of the hybrid composite by changing the fibre orientation at testing parameter P1.

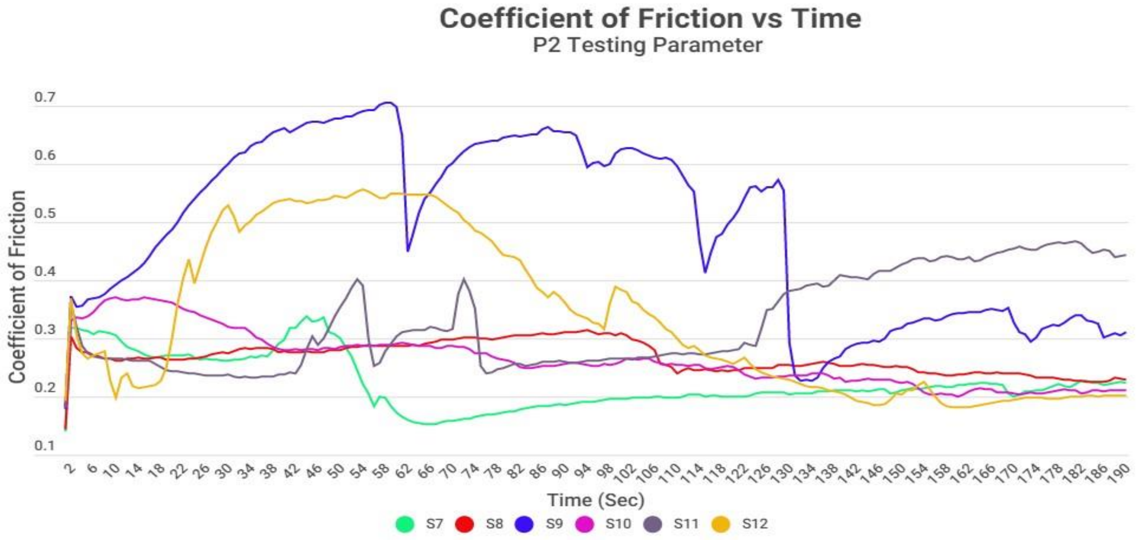

Fig 4.5 (b) Coefficient of friction vs. Time graph of the hybrid composite by changing the fibre orientation at testing parameter P2.

3.2.3 Coefficient of Friction (COF) of the Non-Hybrid Composite Samples

Figures 3.6 (a) and (b) depict the graph between the Coefficient of friction and time of the non-hybrid composite for wear testing parameters P1 and P2, respectively. The C18 sample had the lowest COF at both testing parameters, and the J18 sample had the highest COF in the case of the non-hybrid composite. It is also seen that the higher testing (P1) has a lower COF value compared to the Lower Testing parameter (P1) in the case of non-hybrid composite. The findings highlight the importance of understanding how variations in testing parameters can influence the coefficient of friction in non-hybrid composites.

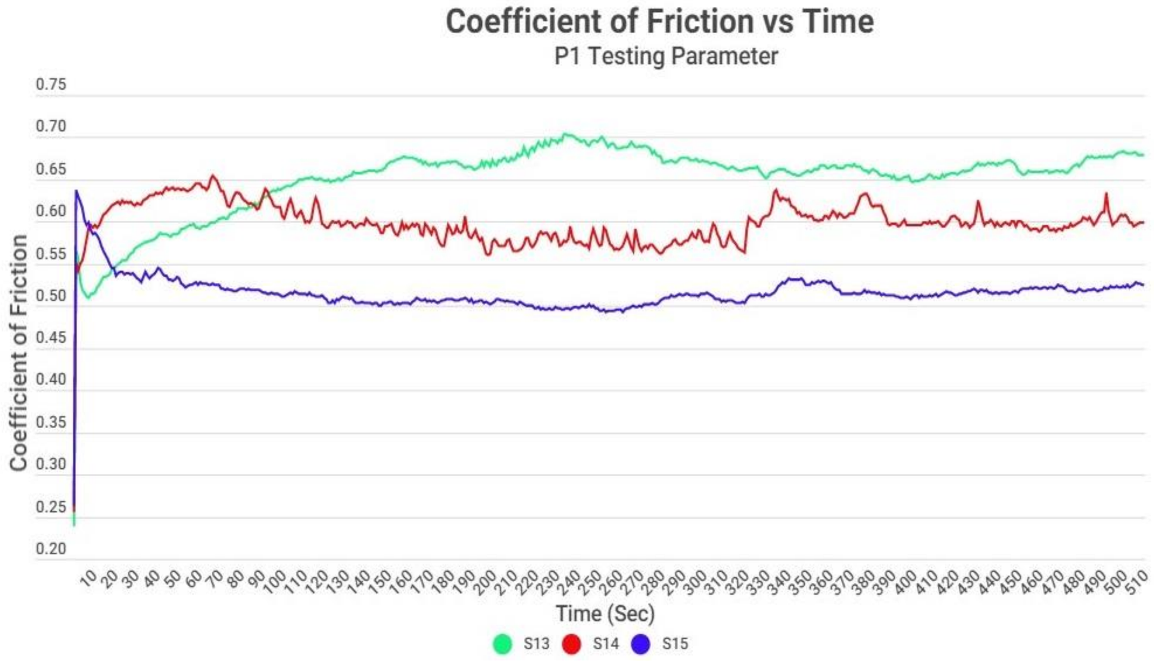

Fig 4.6 (a) Coefficient of friction vs. Time graph of the non-hybrid composite at testing parameter P1.

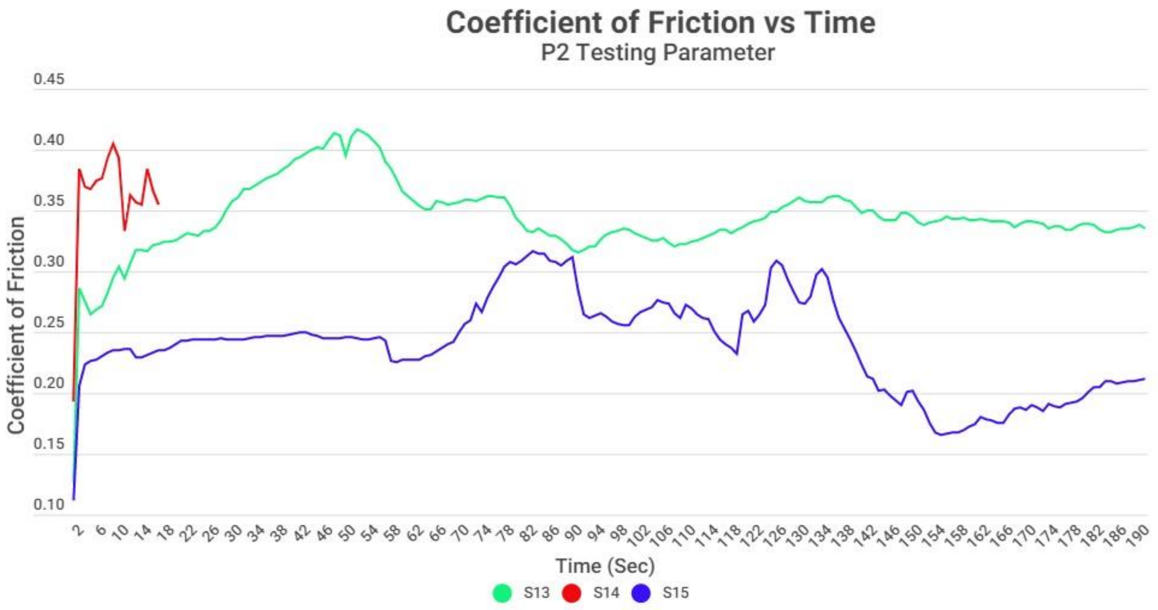

Fig 4.6 (b) Coefficient of friction vs. Time graph of the non-hybrid composite at testing parameter P2.

3.3 Wear Rate of Composite Samples

Figure 3.7 illustrates the wear rate of both hybrid and non-hybrid composite specimens subjected to P2 testing conditions. Among all samples, the non-hybrid J18 (Jute) sample exhibited the highest wear rate, while the hybrid S3 specimen displayed the lowest wear rate measuring approximately 0.0133*10-6 (g/cm). Samples S1, S2, and S10 showcased minimal wear rates, It is quite close to the S3 specimen. . The data presented in Figure 3.7 clearly indicates the varying wear rates of different composite samples under the specified testing conditions.

The results suggest that the hybrid composition of the S3 specimen may have contributed to its significantly lower wear rate compared to the non-hybrid J18 (Jute) sample. The observations highlight the importance of material composition in determining the wear characteristics of composite materials under specific testing conditions.

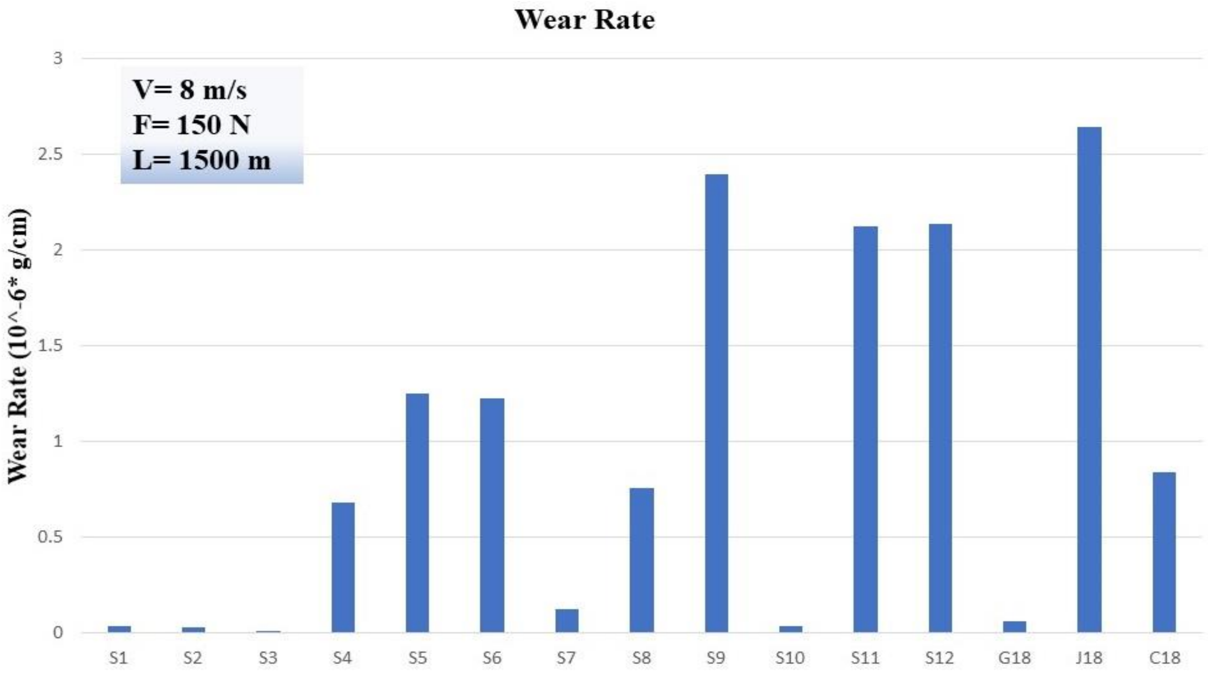

Fig 4.7 Wear rate of the composite samples at testing parameter P2.

3.4 Specific Wear Rate of Composite Samples

Figures 3.8 (a) and (b) illustrate the specific wear rates of hybrid and non-hybrid composite samples about the wear testing parameters P1 and P2, respectively. The data presented in Figure 3.8(a) indicates that specimen S1, featuring a three-layer unidirectional carbon fibre arrangement as the face material, exhibits a minimum specific wear rate of 15.27×10-6 mm3/N-m, while the maximum value, observed in the S12 specimen, reaches approximately 268.08×10-6 mm^3/N-m under conditions of a 20N applied load, 2 m/s sliding speed, and 1000 m sliding distance.

Conversely, Figure 3.8 (b) highlights that the lowest specific wear rate was recorded in the S3 specimen at around 23.5×10-6 mm^3/N-m. On the other hand, the highest specific wear rate was identified in the J18 specimen when subjected to a 150 N applied load, 8 m/s sliding velocity, and 1500 m sliding distance.

Notably, specimens such as S1 and S2, characterized by unidirectional carbon fibre in the uppermost layer, as well as the S7 specimen with a three-ply carbon fibre cross-ply arrangement (90^0, 0^0, and 90^0), and the S10 specimen with a three-layer carbon fibre angle ply arrangement (0^0, 30^0, and 45^0) in the top layer, demonstrate enhanced wear resistance across both sets of testing parameters.

DOI: 10.17148/IARJSET.2024.111116

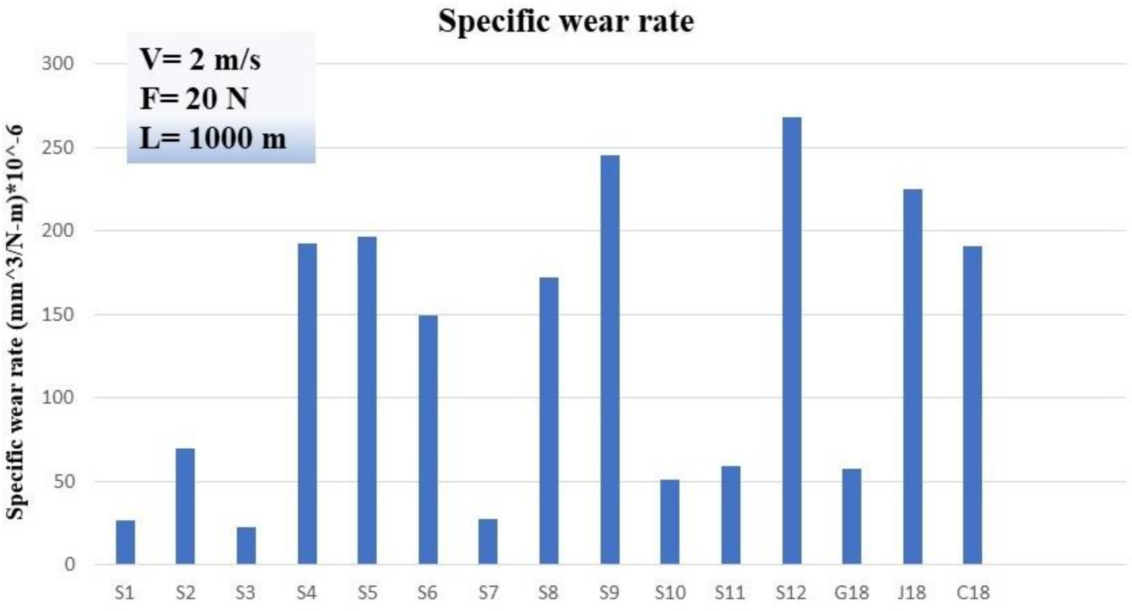

Fig 4.8 (a) Specific wear rate of the composite samples at testing parameter P1.

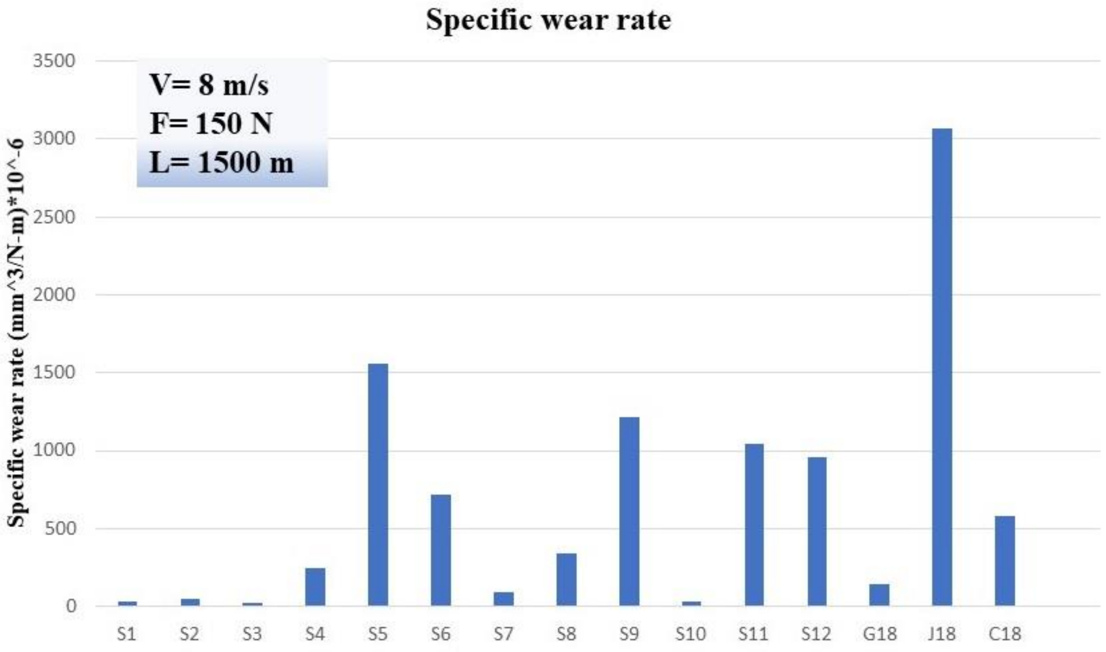

Fig 4.8 (b) Specific wear rate of the composite samples at testing parameter P2.

IV. CONCLUSION

The current study delves into an examination and comparison of the tribological properties of a hybrid composite consisting of jute/carbon/glass epoxy with a non-hybrid composite. The research explores the influence of fiber orientation and stacking sequence on the tribological behavior of the hybrid composite comprised of jute, carbon, and glass epoxy. The selection of stacking sequence has the potential to influence stress distribution, resistance to delamination, and overall mechanical characteristics of the composite material. Fibers that are oriented parallel to the direction of sliding typically provide increased load-bearing capacity and decreased friction coefficients in comparison to fibers that are aligned perpendicular to the sliding direction.

DOI: 10.17148/IARJSET.2024.111116

The orientation of fibers has an impact on the contact area, distribution of stress, and interactions at the interfaces between fibers and the sliding surface. The wear loss of the non-hybrid composite samples J18 was found to be the highest among all, whereas the samples S1, S2, and S3, featuring jute in the central layer and glass or carbon fiber on the outer layers, exhibited the least amount of wear. The stacking sequence plays a more significant role in influencing the tribological properties than the orientation of the fibers. When compared to the non-hybrid composite, the hybridized carbon/glass/jute epoxy composite demonstrates enhanced wear characteristics, indicating the importance of hybridization in improving the performance of composite materials.

Particularly, the hybrid composite design incorporating glass and carbon fibers in the outer layer displays superior tribological properties compared to the composite with jute fiber in the outer layer. The epoxy matrix within the composite serves a crucial role in influencing its lubricating properties by acting as a protective barrier between the individual fibers.

Due to its graphite-like structure, carbon fiber exhibits some inherent self-lubricating properties, leading to lower wear rates in comparison to other types of fibers commonly used in composites. On the contrary, glass and jute fibers may not contribute significantly to self-lubrication, often necessitating additional lubrication in scenarios involving substantial sliding motion. In the case of non-hybrid composites, the G18 sample, consisting of 18 layers of glass fiber, displayed the lowest wear rate among the tested samples.

The poor adhesion of jute fiber to the matrix, positioning it in the central layer of the composite structure can potentially enhance the tribological characteristics of the hybrid material. The jute fiber exhibits inadequate adhesion characteristics with the matrix material, which can result in reduced overall mechanical properties and structural integrity of the composite material. Moreover, this poor bonding can lead to delamination issues and premature failure of the composite structure. Enhancing the adhesion capacity of jute fiber can be achieved through surface treatments, which play a crucial role in improving the surface integrity of the composite material and ultimately enhancing its overall performance.

REFERENCES

[1] S. Acharya, T. Bera, V. P. and S. Pradhan, “Effect of stacking sequence on the tribological behaviour of jute-glass hybrid epoxy composite,” *Materials Today: Proceedings,* 2020.

[2] M. Sharma, H. Sharma and S. Shannigrahi, “Tribology of advanced composites/biocomposites materials,” in *Biomedical Composites,* Elsevier Ltd., 2017, pp. 413-429.

[3] A. K. Kaw, Mechinics of Composite Materials, Taylor & Francis Group, 2006.

[4] T. Madhusudhan, D. M. Senthilkumar and A. D, “MECHANICAL CHARACTERISTICS AND TRIBOLOGICAL BEHAVIOUR STUDY ON NATURAL - GLASS FIBER REINFORCED POLYMER HYBRID COMPOSITES: A REVIEW,” *International Research Journal of Engineering and Technology (IRJET),* vol. 3, no. 4, pp. 2243-2246, 2016.

[5] E. Omrani, P. L. Menezes and P. K. Rohatgi, “State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world,” *Engineering Science and Technology an International Journal,* pp. 1-20, 2015.

[6] A. Shalwan and B. Yousif, “In State of Art: Mechanical and tribological behaviour of polymeric composites based on natural fibres,” *Materials and Design,* pp. 1-11, 2012.

[7] G. Rangasamy, S. Mani, S. K. S. Kolandavelu and M. S. Alsoufi, “An extensive analysis of mechanical, thermal and physical properties of jute fiber composites with different fiber orientations,” *Case Studies in Thermal Engineering,* 2021.

[8] A. Irawan and I.W. Sukania, “Tensile strength of banana fiber reinforced epoxy composites materials,” *Appl. Mech. Mater.,* vol. 776, p. 260–263, 2015.

[9] S. Kumar, K. K. S. Mer, B. Gangil and V. K. Patel., “Synergy of rice-husk filler on physico-mechanical and tribological properties of hybrid Bauhinia-vahlii/sisal fiber reinforced epoxy composites,” *journal of material research and technology,* pp. 2070-2082, 2019.

[10] M. Alajmi, K. Alrashdan, T. Alsaeed and A. Shalwan, “Tribological characteristics of graphite epoxy composites using adhesive wear experiments,” *Journal of Materials Research and Technology,* vol. 9, no. 6, pp. 13671-13681, 2020.

[11] H. Rangaswamy, H. H. M, D. Y. Pimenov, K. Giasin, S. Wojciechowski and M. P. G. Chandrashekarappa,

"Experimental investigation and optimization of compression moulding parameters for MWCNT/glass/kevlar/epoxy composites on mechanical and tribological properties," *Journal of Materials Research and Technology,* pp. 327-341, 2021.

[12] S. Khandaia, R. Nayak, A. Kumar, D. Das and R. Kumar, "Assessment of Mechanical and Tribological Properties of Flax/Kenaf/Glass/Carbon Fiber Reinforced Polymer Composites," *Materials Today: Proceedings,* vol. 18, p. 3835–3841, 2019.

[13] J. Cao and Y. Luo, "Study on tribological properties of epoxy resin composites," *Journal of physics,* vol. 2256, no. 1, pp. 012014-012014, 2022.

[14] "Effect of silanizion on mechanical and tribological properties of kenaf-carbon and kenaf-glass hybrid polymer composites," *Materials Today: Proceedings,* 2020.

[15] M. H. Moosa, M. Abu-Okail, A. Abu-Oqail and S. A. Al-Shelkam, "Structural and Tribological Characterization of Carbon and Glass Fabrics Reinforced Epoxy for Bushing Applications Safety," *Polymers,* vol. 15, no. 9, pp. 2064-2064, 2023.

[16] Z. E. Kennedy and A. I. R. M, "Influence of stacking sequence and hybridization on the mechanical and tribological properties of glass and jute fiber composites," *Materials Today: Proceedings*, 121.

[17] C. Rao, S.Madhusudan, G. Raghavendra and E. V. Rao, "Investigation in to Wear behavior of coir Fiber Reinforced Epoxy Composites with the Taguchi Method," *International Journal of Engineering Research and Applications,* vol. 2, no. 5, pp. 371-374, 2012.

[18] S. Behera, R. K. Gautam, S. Mohan and A. Chattopadhyay, "Mechanical and tribological properties of chemically modified jute/epoxy composites," *Plastics Rubber and Composites,* vol. 52, no. 7, pp. 402-414, 2023.

[19] S. Dalbehera and S.K.Acharya, "Effect of cenosphere addition on erosive wear behaviour of jute-glass reinforced composite using taguchi experimental design," *Materials Today: Proceedings* , p. 2389 – 2398, 2015.

[20] H. A. Ameen, K. S. Hassan and E. M. M. Mubarak, "Effect of loads, sliding speeds and times on the wear rate for different materials," *AMERICAN JOURNAL OF SCIENTIFIC AND INDUSTRIAL RESEARCH,* 2011.

[21] Z. Yanga, Z. Guo and C. Yuan, "Effects of MoS2 microencapsulation on the tribological properties of a composite material in a water-lubricated condition," *Wear,* 2019.

[22] L. F. Toth, J. Sukumaran, G. Szebenyi, A. Kalacska and D. Fauconnier, "Large-scale tribological characterisation of eco-friendly basalt and jute fibre reinforced thermoset composites," *Wear,* 2020.

[23] S. J. I. Raja and S. Sivaganesan, "Experimental investigation on wear properties with micro-structure behavior of arecanut reinforced polymer composite material," *Materials Today: Proceedings,* 2020.

[24] Z. E. Kennedy and A. I. R. M, "Influence of stacking sequence and hybridization on the mechanical and tribological properties of glass and jute fiber composites," *Materials Today: Proceedings,* 2021.

[25] P. Borah and S. Samanta, "Wear behaviour of glass/jute hybrid epoxy composites with addition of fillers," *Advances in Materials and Processing Technologies,* 2020.

[26] M. Venkatesan, K. Palanikumar and S. R. Boopathy, "Experimental investigation and analysis on the wear properties of glass fiber and CNT reinforced hybrid polymer composites," *Sci Eng Compos Mater 2,* vol. 25, no. 5, 2018.

[27] K. S. Ahmed, S. S. Khalid, V. Mallinatha and S. A. Kumar, "Dry sliding wear behavior of SiC/Al2O3 filled jute/epoxy composites," *Materials and Design,* pp. 306-315, 2012.

[28] H. A. Al-Tameemi, A. A. H. Ali and B. Hussein, "Investigation of wear resistance for variable configurations of woven glass-fiber reinforced composite materials," *Materials Research Express,* 2020.

[29] P.Rajasekhar, G.Ganesan and C.Senthilkumar, "Studies on Tribological Behavior of Polyamide Filled Jute Fiber-Nano-ZnO Hybrid Composites," *Procedia Engineering* , p. 2099 – 2109, 2014.

[30] M. SATHIYAMOORTHY and S. SENTHILKUMAR, "Mechanical, thermal, and water absorption behaviour of jute/carbon reinforced hybrid composites," *Sådhanå(Indian Academy of Sciences),* 2020.

[31] L. Zhengjie, X. Qi, C. Liu, B. Fan and X. Yang, "Particle size effect of PTFE on friction and wear properties of glass fiber reinforced epoxy resin composites," *Wear,* vol. 532, no. 205104, 2023.

[32] H. Jagadeesh, P. Banakar, P. Sampathkumaran, R. R. N. Sailaja and J. K. Katiyar, "Influence of nanographene filler on sliding and abrasive wear behaviour of Bi-directional carbon fiber reinforced epoxy composites," *Tribology International,* p. 192, 2024.

[33] L. Mao, Y. Jiao, H. Geng and Y. T. s. composites, "Understanding friction and wear properties of carbon fiber/epoxy," *Composites Part A,* vol. 169, no. 107501, 2023.

[34] O. A. Balogun, O. O. Daramola, A. A. Adediran, A. A. Akinwande and O. S. Bello, “Investigation of Jute/Tetracarpidium conophorum reinforced polypropylene composites for automobile application: Mechanical, wear and flow properties,” *Alexandria Engineering Journal,* vol. 65, pp. 327-341, 2023.

[35] A. K. Bandaru, A. K. Kadiyala and P. M. Weaver, “Mechanical and abrasive wear response of PTFE coated glass fabric composites,” *Wear,* no. 203267, p. 450, 2020.

[36] Y. Xi, C. A. Hill, Z. Xiao, H. Militz and C. Mai, “Silane coupling agents used for natural fiber/polymer composites: A review,” *Composites: Part A,* vol. 41, pp. 806-819, 2010.

[37] S. Vishwas, S. Singh and P. K. Gupta, “Influence of Stacking Sequence and Hybridization on the Tribological Properties of Jute/Carbon/Glass Epoxy Composite,” in *Recent Advances in Materials Technologies, Lecture Notes in Mechanical Engineering*, Springer Nature Singapore Pte Ltd, 2023, pp. 141-152.

[38] C. E. C. Isabel, C. T. M. Victoria, P. Gañán and J. Alonso.4 October 2018.