Jurnal Tribologi 46 (2025) 168-181

MYTRIBOS
Malaysian Tribology Society

Jurnal Tribologi

Website : jurnaltribologi.mytribos.org e-issn: 2289-7232

Fabrication and tribological characterization of Jute-fibre reinforced epoxy composites with pistachio-vera nut shell powder as filler material

Shezan Malik [1], Asrar Rafiq Bhat [1], R. K. Mishra [1], Kaleem A. Najar [2*], Yogesh Singh [3]

[1] School of Mechanical Engineering, SMVDU, Jammu & Kashmir, INDIA.
[2] Institute of Technology Zakura, Kashmir University, Jammu and Kashmir, INDIA
[3] Department of Computer Science Engineering, Sikkim Manipal University, Gangtok, INDIA.
*Corresponding author: najar.kaleem@gmail.com

KEYWORDS

Composite
Epoxy polymer
Jute-fibre
Pistachio-vera nut shell
Biodegradable
Tribology

ABSTRACT

The growing interest in sustainable materials has driven the development of natural fibre-reinforced polymer composites for structural and tribological applications. In this study, novel epoxy-based composites were fabricated by incorporating Jute fibre (10–40 wt.%) and Pistachio-vera nutshell powder (0–30 wt.%) as reinforcements, in the epoxy matrix. Five different composite formulations, including neat epoxy, were prepared using the hand lay-up technique. Tribological performance was evaluated using a pin-on-disc tribometer under varying loads and sliding velocities. Results revealed that hybrid composites containing 20 wt.% Jute fibre and 20 wt.% Pistachio filler exhibited the highest improvement in wear resistance by 62.5% and 73.3% at 10 N and 30 N loads, respectively, compared to the non-hybrid composites. The coefficient of friction (COF) was observed to be highest in the non-hybrid composite and decreased with appropriate filler hybridization. Owing to their enhanced wear resistance, reduced frictional behavior and self-lubricating nature, the developed composites demonstrate strong potential for use in diverse tribological applications.

Received 31 January 2025; received in revised form 12 April 2025; accepted 29 April 2025.
To cite this article: Najar et al. (2025). Fabrication and tribological characterization of Jute-fibre reinforced epoxy composites with pistachio-vera nut shell powder as filler material. Jurnal Tribologi 46, pp.168-181.

1.0 INTRODUCTION

In recent years, the demand for sustainable and environmentally friendly materials has driven significant interest in natural fiber-reinforced composites, which combine natural fibers like jute, flax, and hemp with various polymer matrices. Due to their biodegradability, low cost, and favorable mechanical properties, natural fiber composites have gained widespread attention for applications in automotive, construction, and packaging industries. The Pistachio is originated from interior desert regions because it needs hot and long summers to mature its fruit, can withstand salt and dryness, and requires chilling during winter (Kashaninejad & Tabil,2011). To design the machinery for processing, transportation, sorting, storage and separation, it is crucial to consider the physical properties of Pistachio's kernel and the Pistachio nut. Without taking these factors into account, it may be difficult to design such equipment with good outcomes. Therefore, identifying and taking into account these qualities is essential (Kashaninejadet al., 2006). The shell of the Pistachio-Vera nut offers prospects for the creation of adhesives and thermal insulation. To assure sustainable and green manufacturing that is environmentally sound, economically feasible, and socially beneficial. In order to reduce the usage of synthetic filler, biodegradable polymer composites can be made from agricultural by-products, which are justified by the global desire for clean energy and a greener environment (German, 2016; Paul & Dai, 2018). Further, mineral and synthetic oils can be used as lubricants have been proved from the recent experimental tests (Yahaya et al., 2024).

The newest research is assisting in the construction of hybrid composites made of synthetic and natural fibres. Hybrid composites are composite materials made up of many fibre types or fibre/filler combinations (Khan& Jawaid, 2023). Techniques for combining these fibres include stacking layers of fibres, mixing two different types of fibres in the same layer to form an interplay hybrid, placing fibres selectively where they are needed for increased force, and putting each fibre in a specific direction (Pegoretti et al., 2004).In order to produce the best composite materials for effective use in particular applications, many researchers have achieved success by changing the orientation, fibre content, manufacturing processes or size. But these composite materials might deviate from their intended specifications due to some flaws, like manufacturing flaws, which lowers their mechanical performance. Manufacturing flaws include things like waviness, fibre misalignment, and occasionally breakage, delamination, fibre/matrix de-bonding and the creation of cavities in the matrix of a composite material. It can be eliminated using production parameter optimization in the manufacturing process (Mehdikhani et al., 2019).

Recently developed manufacturing techniques for composites that are automated are robot assistance for processing; leading in complete automation and a large boost in productivity although they are expensive and involve complex machinery (Dickson et al., 2018). For simplicity and ease of processing hand layup technique is a widely used traditional process for fabricating natural fibre reinforced composites. These have been established methods for fabricating composite materials for many years. Given their enormous potential, more natural fibres need to be studied for tribological applications (Shibata et al., 2006). Fibre-reinforced composites are stiff and strong but typically brittle materials that are encased in a softer, more ductile matrix material. They are lightweight and strong materials. When opposed to an unreinforced matrix, the reinforced matrix imparts practical forces to the composite's reinforcing fibers, developing in a composite along better industrial characteristic (Holbery & Houston, 2006). In comparison to the steels and alloys commonly used in structural applications, polymer composites are more affordable, lighter, resistant to corrosion, and have a stronger specific strength. Consequently, the usage of polymer composites in structural components may help eliminate important problems like corrosion and fatigue, which cause the loss of materials and thereby resources (Chin& Yousif, 2009).

The toughening of fibre-reinforced polymer composites has long been an uncertain area of study. To make these materials less brittle and more resistant to degradation, several methods have been suggested. The structure-property connections of biodegradable composites that are particularly resistant to failure have gained attention in the hunt for novel strengthening methods (Nirmal et al., 2010; Swolfs et al., 2014). The stiffness and temperature resistance of polymer fibres are constrained despite their low densities and ductility. Due to the drawbacks of present toughening technologies and the pressing need for novel lightweight materials with higher toughness, "hybridization" research is once again receiving attention. A matrix that has at least two different types of reinforcements is referred to as a hybrid composite (Chaudhary et al., 2018).The banana-reinforced epoxy composites have shown higher tensile and impact strengths with compared to hybrid banana and jute-reinforced epoxy composites, whereas hybrid composites possess higher flexural strengths (Akil et al., 2011).The researchers discovered that kenaf-reinforced composites with a fibre volume %age (approximately 48) increased the wear-resistance by more than 80% when used in standard direction (McLaren& Tabor, 1965). The researchers found that adding natural fibres considerably increased how well clean epoxy withstood wear. When compared to previously used composites, hemp/jute hybrid composites have demonstrated higher wear performance (Randhawa & Patel, 2020). The mechanical properties of natural fibre-based polymer composites are decreased because natural fibres absorb water, causing swelling, de-bonding towards the fibre-matrix interface, and enlarging the space between fibre bundles. Therefore, the mechanical characteristics significantly change when submerged in water for a predetermined amount of time (Bajpai et al., 2013). Long-term exposure to seawater reduced the failure strength of composites made with T-700 carbon fibres and VARTM-based vinyl ester resin by 6%, while barely altering the elastic modulus (Friedrich, 2018).

Epoxy has a higher COF against steel in humid environments because of its adherence to the surface of oxidized metal (Sukur & Onal, 2021). In one investigation, the PTFE had better adherence onto the metallic counterpart when rotated with a steel body, leading to better transfer film formation and a lower COF (Kootsookos & Mouritz, 2004). Wear rates increase in polymers that absorb some water, such as semi crystalline polymers. Semi crystalline polymeric materials become plasticized when water seeps into their amorphous region (Chalmers, 1991). According to a study, the mechanical strength of the bio-composite specimen of nettle-fibre reinforced polypropylene rapidly decreased on the order of 13% following initial exposure to diesel oil (Ahmed et al., 2012). A few examples of the use of polymers in many industries include filament wound bushings for severe environments, slide elements in textile machinery, blend bushings in fuel injection pumps and cages of high-precision ball bearings (Pradhan et al., 2022).

The main objective of this research is the fabrication of a hybrid-polymer composite made from Jute fiber, Pistachio shell powder, and Epoxy polymer to improve its tribological performance. The experimental analysis focuses on how filler hybridization affects the COF and wear behavior of the composites. Jute fiber, in the form of a bidirectional woven mat, was utilized with weight fractions ranging from 0% to 40%, along with varying quantities of Pistachio shell powder and were produced using the hand lay-up method. Furthermore, the studies were carried out to assess the impact of fiber loading, applied force, and sliding velocity on the COF and wear characteristics of the composites. The tribological properties of these novel composite materials have not been previously explored as per the present literature survey. The potential applications of these composites include use in automotive components, machinery parts and other wear-resistant materials, where their enhanced tribological characteristics are important.

2.0 EXPERIMENTAL PROCEDURE

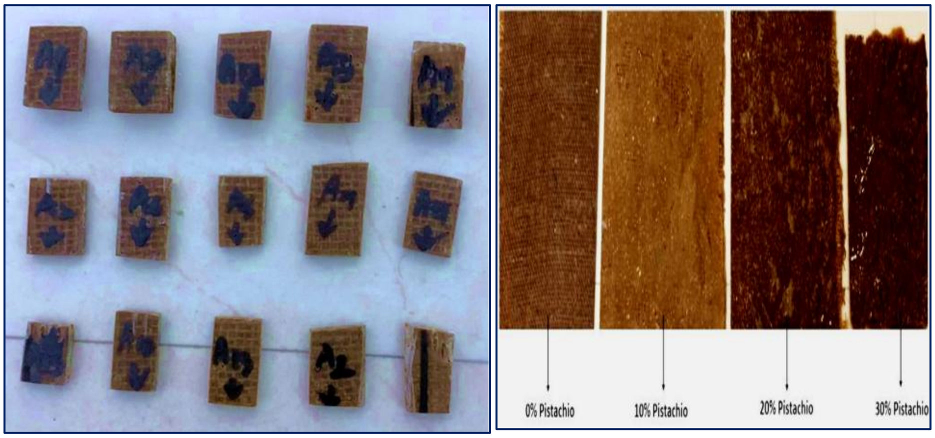
2.1 Composite Fabrication

Jute-fibre was purchased from an online platform in the form of a bi-directional woven mat. Cellulose (64.4%), hemi-cellulose (12%), lignin (11.8%), water make up the chemical makeup of Jute-fibre (10%), water soluble (1.1%), pectin (0.2%) and wax (0.5%). Pistachio-Vera nut shell powder was prepared in a household mixer. The Pistachio-Vera nuts were purchased from a local grocery and the shells were kept in direct sunlight for drying. Afterwards the nut shells were placed in a household mixer from where the powder was obtained of size 300-600 microns. Epoxy Resin (LY556 grade) and Hardener (HY951) was provided by Herenba Instruments & Engineers Ambattur, Chennai, India. The Pistachio nutshell powder, bidirectional Jute-fibre mat, epoxy resin and Hardener are shown in Figure 1 (a, b, c, d), respectively. Each composite was made utilizing the open mould lay-up technique. A 300 × 300 × 5 mm^3 mild-steel mould was used throughout the production. Various fibre weight fractions, including 0 %, 10 %, 20 %, 30 %, and 40 %, were employed. The Jute-fibre mats were trimmed to fit the specifications of the mould. According to the weight percentages of the composite, Pistachio percentages ranged from 0 to 30 %. To prevent sticking and promote simple removal of the composites, they were covered with Teflon sheets at the top and bottom. Epoxy resin was gently blended in a 2:1 ratio with filler and hardener. To prevent composite mixtures to be laid on Teflon sheets from adhering to it, silicon oil was sprayed on them before deposition. On the Teflon sheet, a thin layer of the Epoxy/Pistachio polymer mixture was manually applied. The Epoxy/Pistachio mixture layer was carefully covered with a Jute-fibre mat before another polymer layer was applied. All produced composites used alternate layers of fibre and polymer mixture in accordance with the specification. To protect fibre from the outside environment, the top and bottom layers of all composites were filled with a polymer filler mixture. To evenly disperse polymer throughout the composite, a uniform weight of about 25 kg was applied to it. For approximately 72 hours, composites were left at room temperature for curing. The produced composites were then post-cured for a total of three hours at 60°C. The developed composite's specimens along with the percentage of Pistachio are represented in Figure 2 (a, b). The percentage of the matrix with filler for different fabricated composites is also mentioned in Table 1.

(a) (b)

© (d)

Figure 1: (a) pistachio-vera shell powder; (b) jute fibre mat; (c) epoxy resin; (d) hardener.



(a) (b)

Figure 2: (a) samples cut for testing purposes and (b) composite's specimens along with the percentage of pistachio.

Table 1: Composition of different fabricated composites.

Fabricated Composite	Matrix (%)	Reinforcement (%)	Filler (%)
J0 (Neat Epoxy)	100	0	0
J1-P0	60	40	0
J2-P1	60	30	10
J3-P2	60	20	20
J4-P3	60	10	30

2.2 Tribological Study Methods

The tribologicalcharacteristics of thesynthesizedcomposites was examined usingpin-on-disctype tribometer (ASTM Standard G99, Ducom Wear & Friction Monitor TR-20LE-PHM400),as depicted inFigure 3. A steel disc made of EN-31gradematerial (603 HRC) was utilised for the counter face. A stationary sample held in a holder and a rotating disc slide against one another. These tribological experiments were conducted across a sliding displacement of 1000 m at five different loads (10N, 15N, 20N, 25N & 30N) and at sliding velocities of 1 m/s, 1.5 m/s and 2 m/s to determine their impact on the frictional and wear characteristics. Before every test, samples were first scratched artificallyusingemery paperswith grit sizes; 100, 600, 1500 and 2000. This procedure was adopted in order to achieve continuous starting roughness and closecontact between thesampleand disc. Before the start of each test, samples and the countersurfacewere also cleaned with an acetone solution. The specimen's original weight was noted prior to every experiment. The tribometer's friction monitor continuously displays and records the friction force while the investigation gets underway. Throughout the experiment, tribometer periodically monitored the frictionalforceduringevery 90 seconds. After the test, the used specimens were removed from the holder and cleaned using tissue paper soaked in acetone. Then the samples were air dried, and their final weights were noted. A digital weighing instrument (10^4 gram precision, Digital Mettler Toledo Analytical, capacity: 220gram) was utilized to estimate the weight of testing samples (depicted in Figure 4). The weight loss occurred in every test was calculated from the difference between the sample's initial and final weight measurements. The Table 2 shows the study matrix of each sample (1 - 15) with different input tribological parameters.


(a) (b)

Figure 3: (a) high temperature pin-on-disc tribometer and (b) wear debris of tested composite on counter face.

Figure 4: digital electronic weighing machine with a 10^4 gram precision.

Table 2: Study matrix of each sample (1-15) with different input tribological parameters.

Samples	Load (kg)	Speed (rpm)
A1	1	192
A2	1.5	
A3	2.0	
A4	2.5	
A5	3.0	
A6	1	286
A7	1.5	
A8	2.0	
A9	2.5	
A10	3.0	
A11	1	382
A12	1.5	
A13	2.0	
A14	2.5	
A15	3.0	

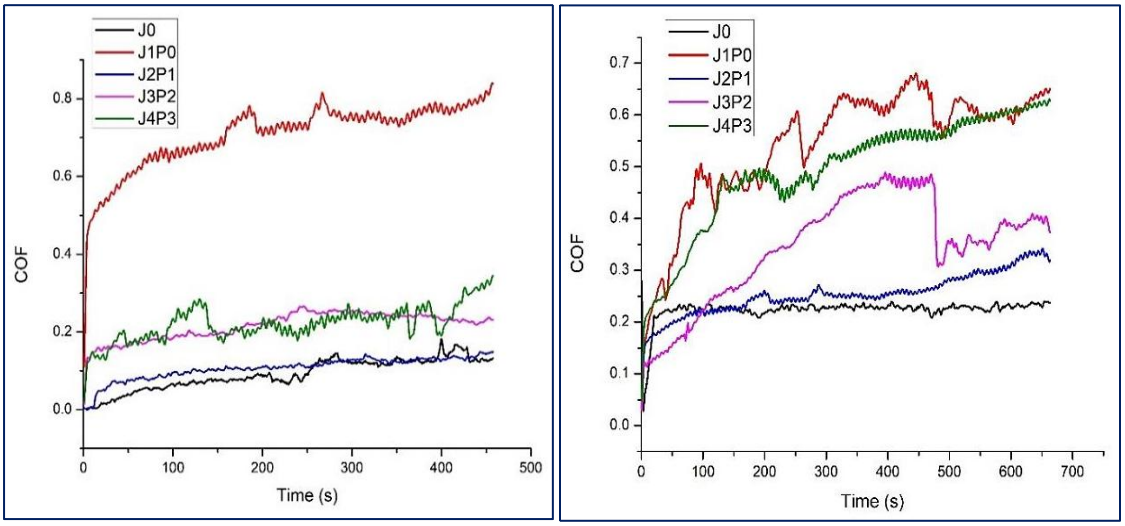
3.0 RESULTS AND DISCUSSION

3.1 Frictional Behavior

Figure 5 (a, b) illustrates the variation of the frictional coefficient as a function of time for each synthesized composite, under the application of load ranging from 10N - 30N. Except for J1P0, a non-hybrid composite containing 40% jute fibre, all produced composites displayed nearly a steady state friction coefficient at the lowest stress (10N). This occurs as an outcome of the specimen's excessive fibre content (40 %). Since there is more fibre contact at the interface as an outcome of the specimen's excessive fibre content and the fact that fibre gives greater resistance than polymer, the coefficient of friction rises over time (Bajpai, et al., 2014).

Compared to pristine epoxy, all jute-reinforced composites have displayed a higher COF value. Compared to J1P0 (a non-hybrid composite) all hybrid composites have lower COF, as described by the filler's tendency to fill-up the voids in the composite, developing best surface quality with minimum friction. The COF starts to rise with additional inclusion due to the dominance of fillers and fibres in the matrix leading to increased surface roughness and hence higher COF. However, this reduction can be achieved when filler powder is added at lower percentages (10%) (Ahmed, et al., 2012). With the exception of J1P0, all developed composites exhibit greater friction coefficients at maximum loads (30N) compared to values at minimum loads (10N), which may be because more fibre is in touch with the counter face in this sample. In the instance of a 10N load, the COF stabilized practically immediately, whereas a 30 N load took 100 seconds. Past research noted similar tendencies as well (El-Tayeb, 2008; Chand, & Dwivedi, 2007). The composites containing 40% Jute-fibre set maximum COF values for both 10 N and 30 N loads. After 200 and 250 seconds of 30N load, an abrupt rise in friction for composites containing 40wt. % of fibre could be seen. The primary cause of this could be asperity breaking, which would increase real area of contact and eventually bring frictional coefficient to a stable condition (Singh & Yousif, 2009; Haq & Anand, 2018). It is evident that the COF for the composite J3P2 (which contains 30% jute and 20% filler) drops after 500 seconds at high loads. The explanation has been taken from the concept of thermal softening of the polymer matrix at peak force, resulting in polymer particles covering the testing surface and eventually decreases the frictional coefficient. Therefore, the value of friction regarding all synthesized composites fluctuates in the range of 0.1 - 0.8, working under the external force of 10-30N.

Figure 5 illustrates how Jute-fibre reinforcing affects COF. With an increase in Jute-fibre loading, the COF rises. All testing loads exhibit the same tendency. In compared to pristine epoxy, the maximum COF for composites containing 40 weights % fibres rose by 150 % and 100 % for 10N and 30N load, accordingly. In this context, an increase in fibre loading results in a larger contact surface between the fibre and the steel counter face, which raises the COF (Edwards, 1998; Kumar, & Anand, 2018).



(a) (b)

Figure 5: COF at (a) minimum load; (b) maximum load (at constant velocity of 1m/s).

Figure 6 shows the variation of frictional coefficient with respect to increase in applied load. The frictional coefficient rises with an increase in applied load up to a certain limit and starts decreasing afterwards. The increased in asperities contact-surface at the interface is responsible for the rise in frictional coefficient. The epoxy polymer's thermal softening may be the possible reason for the drop in COF under a 25N load. Further, there might be the generation of heat when the composite's sliding surface slides on the counter face. The counter face is covered with a thin layer of this thermally softened polymer, which prevents fibre contact with the surface and lowers COF (Nirmal, et al., 2010).It follows that COF rises with an increase in external force up to some limit before begin to fall after that (Chaudhary, et al., 2018).At a normal load of 20N and at the low velocity (1 m/s) and high velocity (2 m/s), the frictional curves for all composites that have been developed as represented in Figure 7 (a, b). Additionally, a rising trend in COF is seen as time goes on due to asperities breaking at the point of contact. For COF at low speed, both non-hybrid composite J0 and hybrid composite J4P3 displayed a steadily rising trend. This can be due to the asperities breaking, which increased the actual contact area. When moving faster, the friction curve for the non-hybrid composite J0 showed strong peaks. At low speed and high speed, the COF is roughly 0.1 - 0.5 and 0.1 - 0.35, respectively. The highest COF is found for J1P0 whereas lowest was found for neat epoxy samples.

Figure 8 illustrates the impact of sliding velocity on frictional coefficient for all synthesized composites under an external force of 20N, which makes it clear that the COF falls as sliding velocity rises. The thermal softening of composite's matrix is responsible for this behavior. The temperature rises when the steel counter body slides along with the composite's face resulting in local melting of polymer that covers the counter face (Paul & Dai, 2018; Ahmed, et al., 2012). In this regard, with the increase in sliding velocity will distort the polymer plastically. The melted polymer layer behaves as a shielding film and leads to the decrease in COF (El-Tayeb, 2008; Kumar & Anand, 2018).

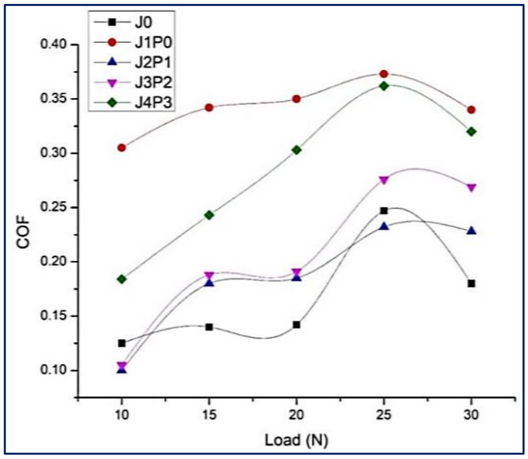
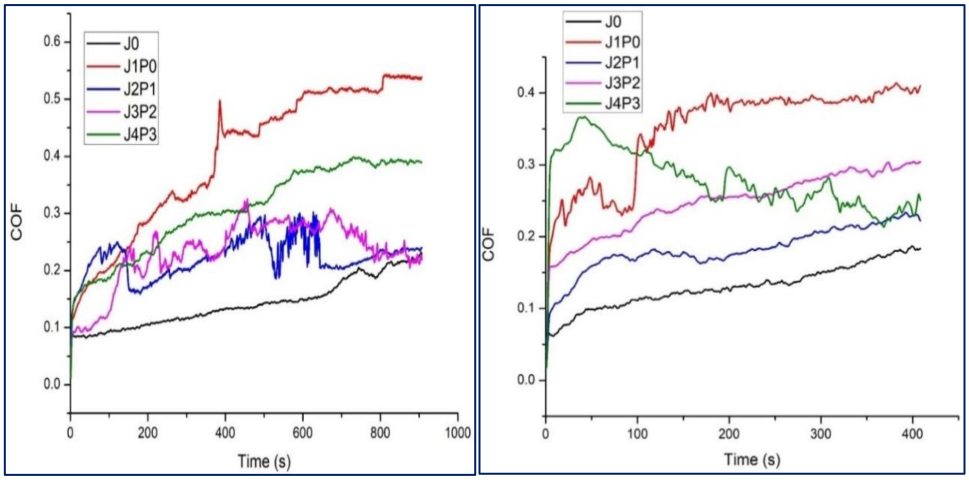


Figure 6: variation of COF with load at different fibre loadings.



(a) (b)

Figure 7: COF at (a) low speed; (b) high speed (at a constant 20 N load).

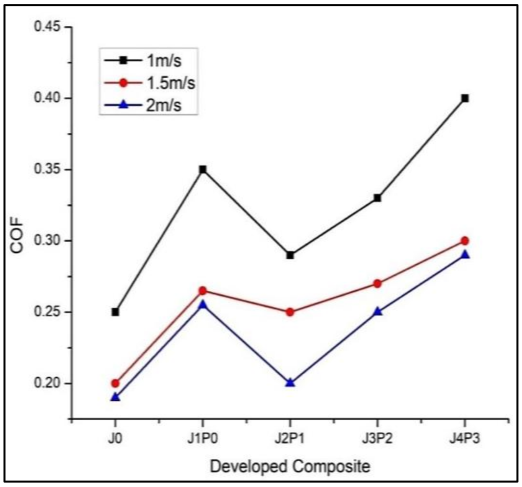


Figure 8: variation of COF with respect to sliding velocity for all fabricated composites.

3.2.1 Wear Behavior

Figure 9 shows the wear rate of synthesized composites under varying external load. This can be clearly confirmed from the graph that the increase in filler percentage of developed composites led to an increase in wear resistance when added up to 20% weight fraction. However, once reinforcement with Jute-fibre reached 20% weight fractions in developed composites, wear resistance began to drop. Additionally, compared to non-hybrid composites, all hybrid composites showed decreased wear loss. The trend is present in all loading scenarios. In comparison with neat epoxy, the wear resistance at the minimum force (10N) is raised by 62.5% for composites consisting of 20% weight by each filler and Jute-fibre (J3P2). At maximum force (30N); composites containing 20% jute and 20% filler showed 73.3% advancement in wear resistance (J3P2). This may be attributable to the enhanced hardness and interfacial adhesion of the fabricated composites, which improved due to rise in fibre loading and addition of Pistachio filler.

The matrix area in contact with the counter face reduces as fibre loading rises, resulting in less wear in reinforced composites. Additionally, this has been also concluded that produced composites outperformed neat epoxy in terms of wear resistance due to increased fibre-matrix interfacial adhesion (Ahmed, et al., 2012). In the instance of polyester composites reinforced with betel-nuts, the presence of a fibre mat improved the wear resistance (Singh& Yousif, 2009). Thus, this reveals that the wear behavior of epoxy composites is remarkably impacted by the fibre reinforcement (Khan & Jawaid, 2023).

It is confirmed from Figure 9 that with the rise in applied force causes the increase in wear loss for developed composites. The results of the experiment are also related to the Archard's wear law (Chand&Dwivedi, 2007; Haq & Anand, 2018). With respect to pristine epoxy, the wear rate for reinforced composites is quite minimal. A larger material loss is seen as the magnitude of external force increases. This might be the result of the steel counter face's strong asperities penetrating the softer composite material (Ahmed, et al., 2012). Additionally, temperature rises with increasing loads, which contributes to greater wear loss (Edwards, 1998). Wear loss for developed composites rises more quickly as the load rises. Here it very clear that plain epoxy is extremely sensitive to load change. For neat epoxy, the slope of the arc is elevated for various loads. This suggests that tidy polymer wear rate is relatively substantial. During the experimentation, it was discovered that tidy epoxy samples began to deform at greater stresses (25N & 30N). This can be a result of frequent, strong axial thrust. Jute reinforced composites did not exhibit this distortion throughout the entire testing. Other researchers have also noticed comparable tendencies (Kumar, & Anand, 2018; Bajpai, et al., 2013; Bahadur, 2000).

For all designed composites, the variation in wear rate with respect to sliding velocity (at 20N applied force) is shown in Figure 10. The image clearly shows that when speed increases, wear loss for the pristine polymers also rises. On the other hand, for all reinforced composites, wear loss diminishes as speed increases. The cause for the rise in wear loss for the neat polymer is higher plastic deformation with increased speed. Good fibre-matrix interfacial bonding is what causes the wear loss to decrease at higher speeds in reinforced composites. A lesser amount of fibre pullout was seen during sliding. Because of the thermal softening at greater speeds a thin polymer film will be formed. This film shields the fibres from pull out and detachment, resulting minimum wear loss (German, 2016, Bhat, et al., 2023).

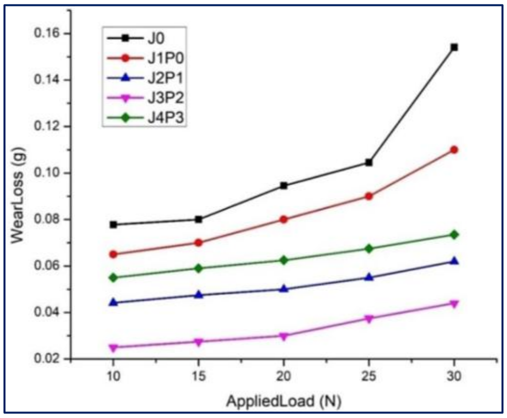


Figure 9: Wear loss for synthesized composites at different loads.

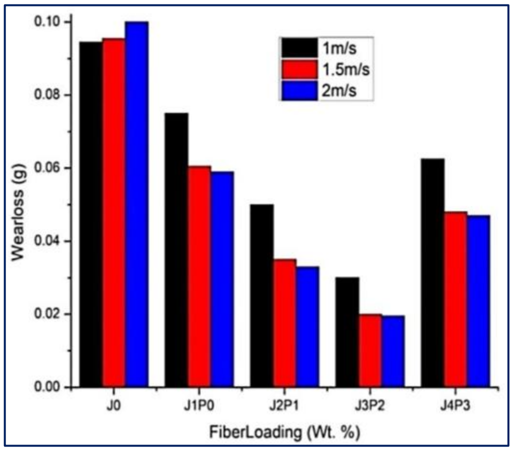


Figure 10: Wear loss of fabricated composites at different sliding speed.

CONCLUSIONS

In this study, epoxy-based hybrid composites were successfully fabricated using varying weight percentages of Jute fibre (10–40 wt. %) and Pistachio-vera nutshell powder (0–30 wt. %) as reinforcements, with the epoxy matrix content fixed at 60 wt. %. The composites were developed via the hand lay-up method and evaluated for their tribological performance to determine their suitability for potential applications in automotive, marine, and other wear-prone environments.

The experimental results revealed that the non-hybrid composite (J1P0) exhibited the highest coefficient of friction (COF), while the incorporation of Pistachio filler into the hybrid composites significantly reduced the COF, particularly at both low (10 N) and high (30 N) applied loads. Among the hybrid formulations, the COF initially increased with the addition of filler up to 10 wt. % but declined with further increase, owing to improved surface lubrication and reduced roughness. COF was also observed to increase with load (ranging from 0.1 to 0.8), while it decreased with increasing sliding velocity—recorded between 0.25–0.40 at 1 m/s and 0.1–0.275 at 2 m/s.

Wear resistance was significantly enhanced in the hybrid composites, with the J3P2 formulation (20 wt. % Jute, 20 wt. % filler) showing the highest improvement—62.5% and 73.3% under 10 N and 30 N loads, respectively—compared to the non-hybrid composite. Conversely, the composite with the highest filler content (J4P3) exhibited increased wear loss, likely due to elevated porosity. Across all samples, wear loss increased with applied load but decreased with higher sliding velocities.

Overall, the developed hybrid composites demonstrated superior tribological properties, including low friction, enhanced wear resistance, self-lubricating behavior, and potential corrosion stability. These attributes make them promising candidates for a wide range of tribological applications.

ACKNOWLEDGMENTS

The authors would like to thank the School of Mechanical Engineering (SMVDU Jammu, India) for proving us the facilities regarding the synthesis and characterization of novel composites mentioned in this research work.

REFERENCES

Ahmed, K. S., Khalid, S. S., Mallinatha, V.& Kumar, S. A. (2012). Dry sliding wear behavior of SiC/Al2O3 filled jute/epoxy composites. Materials and Design, 36, 306-315.

Akil, H. M., Omar, M. F., Mazuki, A. M., Safiee, S. Z. A. M., Ishak, Z. M.& Bakar, A. A. (2011).Kenaf fiber reinforced composites: A review. Materials and Design, 32, 4107-4121.

Bahadur, S. (2000). The development of transfer layers and their role in polymer Tribology. Wear, 245, 92-99.

Bajpai, P. K., Meena, D., Vatsa, S.& Singh, I. (2013). Tensile behavior of nettle fiber composites exposed to various environments. Journal of Natural Fibers, 10, 244-256.

Bajpai, P. K., Singh, I.& Madaan, J. (2013). Frictional and adhesive wear performance of natural fibre reinforced polypropylene composites. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 227, 385-392.

Bajpai, P. K., Singh, I.& Madaan, J. (2014). Development and characterization of PLA-based green composites: A review. Journal of Thermoplastic Composite Materials,27, 52-81.

Bhat, A. R., Kumar, R.& Mural, P. K. S. (2023). Natural fiber reinforced polymer composites: A comprehensive review of tribo-mechanical properties. Tribology International, 189, 108978.

Chalmers, D. W. (1991). Experience in design and production of FRP marine structures. Marine Structures, 4, 93-115.

Chand, N.& Dwivedi, U. K. (2007). Influence of fiber orientation on high stress wear behavior of sisal fiber-reinforced epoxy composites. Polymer Composites,28, 437-441.

Chaudhary, V., Bajpai, P. K.& Maheshwari, S. (2018). An investigation on wear and dynamic mechanical behavior of jute/hemp/flax reinforced composites and its hybrids for tribological applications. Fibers and Polymers, 19, 403-415.

Chin, C. W.& Yousif, B. F. (2009). Potential of kenaf fibres as reinforcement for tribological applications. Wear,267, 1550-1557.

Dickson, A. N., Ross. K. A.& Dowling, D. P. (2018). Additive manufacturing of woven carbon fibre polymer composites. Composite Structures,206, 637-643.

Edwards, K. L. (1998). An overview of the technology of fibre-reinforced plastics for design purposes. Materials and Design, 19, 1-10.

El-Tayeb, N. S. M. (2008). A study on the potential of sugarcane fibers/polyester composite for tribological applications. Wear, 265, 223-235.

Friedrich, K. (2018). Polymer composites for tribological applications. Advanced Industrial and Engineering Polymer Research, 1(1), 3-39.

German, R. M. (2016).Particulate composites. Springer Nature, https://doi.org/10.1007/978-3-319-29917-4, 198-200.

Haq, M. I. U.& Anand, A. (2018). Dry sliding friction and wear behaviour of hybrid AA7075/Si3N4/Gr self lubricating composites. Materials Research Express,5(6), 066544.

Holbery, J.&Houston, D. (2006). Natural-fiber-reinforced polymer composites in automotive applications. JOM, Springer Nature,58, 80-86.

Kashaninejad, M. & Tabil, L. G. (2011). Postharvest biology and technology of tropical and subtropical fruits. Woodhead Publishing, 247e, 218-247.

Kashaninejad, M., Mortazavi, A., Safekordi, A.& Tabil, L. G. (2006). Some physical properties of pistachionut and its kernel. Journal of Food Engineering,72 (1), 30-38.

Khan, T.& Jawaid, M. (2023). Green Hybrid Composite in Engineering and Non-Engineering Applications. Springer Nature,https://doi.org/10.1007/978-981-99-1583-5,1-13.

Kootsookos, A.& Mouritz, A. P. (2004). Sea water durability of glass- and carbon-polymer composites. Composites Science and Technology, 64, 1503-1511.

Kumar, R.& Anand, A. (2018). Dry sliding friction and wear behavior of ramie fiber reinforced epoxy composites. Materials Research Express, 6(1), 015309.

McLaren, K. G.& Tabor, D. (1965). Friction of polymers at engineering speeds: influence of speed, temperature and lubricants. Wear, 8, 79-83.

Mehdikhani, M., Gorbatikh, L., Verpoest, I.& Lomov, S. V. (2019). Voids in fiber-reinforced polymer composites: A review on their formation, characteristics, and effects on mechanical performance. Journal of Composite Materials, 53, 1579-1669.

Nirmal, U., Yousif, B. F., Rilling, D.& Brevern, P. V. (2010). Effect of betelnut fibres treatment and contact conditions on adhesive wear and frictional performance of polyester composites. Wear,268, 1354-1370.

Paul R. & Dai L. (2018). Interfacial aspects of carbon composites. Composite Interfaces, 25, 539-605.

Pegoretti, A., Fabbri, E., Migliaresi, C.& Pilati, F. (2004). Intraply and interply hybrid composites based on E-glass and poly (vinyl alcohol) woven fabrics: tensile and impact properties. Polymer International. 53, 1290-1297.

Pradhan, S., Prakash, V.& Acharya, S. K. (2022). Bio waste (Pistacia vera nut shell) filled polymer composites for tribological applications. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications,236, 334-344.

Randhawa, K. S.& Patel, A. D. (2020). Influence of boric anhydride reinforcement on mechanical properties and abrasive wear of nylon 6. Materials Research Express,7(5), 055303.

Shibata, S., Cao, Y. & Fukumoto, I. (2006). Lightweight laminate composites made from kenaf and polypropylene fibres. Polymer Testing,25, 142-148.

Singh, G. N.& Yousif, B. F. (2009). Wear and frictional performance of betelnut fibre-reinforced polyester composite. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 223, 183-194.

Sukur, E. F.& Onal, G. (2021). Long-term salt-water durability of GNPs reinforced basalt-epoxy multiscale composites for marine applications. Tribology International,158, 106910.

Swolfs, Y., Gorbatikh, L.& Verpoest, I. (2014). Fibre hybridisation in polymer composites: A review. Composites Part A: Applied Science and Manufacturing, 67, 181-200.

Yahaya, A., Samion, S., Mariam, S. & Paiman, Z. (2024). Tribological characteristics of palm olein under conditions of elevated temperature and effect of addition molybdenum disulfide at high load. Jurnal Tribologi, 43, 17-30.