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THE INFLUENCE OF GRIT SIZE AND FIBER LENGTH ON THE FRICTIONAL PERFORMANCE OF COIR FIBER-REINFORCED POLYMER COMPOSITE

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Abstract: *There is a strong need to research and create innovative eco-materials for many engineering applications. The majority of engineering elements are subjected to tribological loading conditions during service. The work uses abrasive friction loading conditions to explore natural fiber-reinforced polymer composites. Three distinct fiber lengths—5 mm, 10 mm, and 15 mm—were used to create coir fiber-reinforced epoxy composites. Coir and epoxy resin are treated on their surfaces with alkali to increase their effectiveness. Normally applied loads of 5N, 10N, 15N, and 20N, and sliding Typically, durations of 0, 2, 4, 6, 8, and 10 minutes are adjusted this way. Friction behavior is tested on BOR at standard room temperature and 1.9 m/s sliding velocity. Values for frictional behavior are listed for various applied loads, fiber lengths, and grades. SEM is used to investigate surface topography. Comparatively, the minimum coefficient of friction value is 0.062 for a 5mm fiber length under a 5N normal applied load of Grade 400. In contrast, the highest Friction coefficient is measured to be 1.592 for grade 600 and a typically applied load of 20N for various fiber lengths.*

Keywords: *natural fibers, composites material, friction performance, alkali treatment.*

1. INTRODUCTION

Natural fiber composites are more affordable and biodegradable than synthetic fiber composites. Some studies have concentrated on the reinforcement criteria for better-reinforced polymer composites since natural fibers are readily available and best suited for manufacture [1, 2]. Researchers have been working to substitute synthetic fibers with natural ones for the past few years as these natural fibers offer higher attributes, including high specific mechanical properties and renewable resources, with low cost [3, 4]. These natural fiber-reinforced polyester composites outperform synthetic fiber materials in tribology [5]. The friction coefficient and wear resistance are necessary even for industrial applications like bearings, brake pads, and flooring materials [6]. Natural fibers reinforced by polymer composites are in high demand because they have superior environmental characteristics, are more affordable, and are simpler to manufacture than synthetic fibers [7, 8]. Polymer composite is employed in the construction, automobile, and furniture sectors because of their excellent properties [9].

Such polymer natural composites are differentiated by their special qualities of flexible processing equipment, low cost and density, and the best mechanical characteristics with high strength chemically resistant than synthetic fibers [10, 11]. Natural fibers, including coir, sisal, silk, and date palm, would be preferable to synthetic fibers for polymer composite matrix in the current context [12]. There is a rise in research on natural fiber-reinforced composites for mechanical, biological, and other purposes. [13-15]. Such natural fiber-reinforced composite polymers can improve their performance in friction, flexural, wear, impact, tensile, and other mechanical as well as tri-biological applications [16–18].

Studies are being conducted on how fiber materials, additives, and additional changes and their content percentages influence the mechanical, chemical, & biological properties of polymer composites [19]. The relationship between mechanical, tri-biological, and academic studies on the performance of materials is still up for discussion [20–22]. However, carbon has certain unique, selective effects on mechanical performance, although it is more advantageous in terms of frictional characteristics [23]. The wear resistance of coir fibers mostly depends on dust particles' size and the typical load being applied, according to research by Aireddy [24] on coir epoxy composite with different ratios. Additionally, he claimed that reinforcing dominated the wear process due to the high coir dust loading [25].

D. Verma [26] researched rice husk-reinforced epoxy composite and discovered better outcomes on wear loss of abrasive with appropriate treatment [27]. Palm and dry mango leave also enhance the tribological properties of polyester composites [28, 29].

Coir fibers are suggested with reinforced polymer composites in our current study to improve the friction behavior of the suggested composite materials.

2. MATERIALS & METHODS

2.1 Alkali Treatment for the Fiber Materials

These coir fibers are alkali-treated for better enhancements in their physical and mechanical properties. These fibers are prewashed in water and then faded at room temperature in this procedure. This procedure comprises immersing coir fibers in a 5 percent weight/volume Na OH aqueous solution for approximately three hours at a temp. of 700°C.These treated coir fibers are then removed from the solution and submerged in 5% acetic acid, a neutralizer. Afterward, as shown in Fig 1, these are soaked in water and left to dry in the electric oven at 1100°C for two hours.

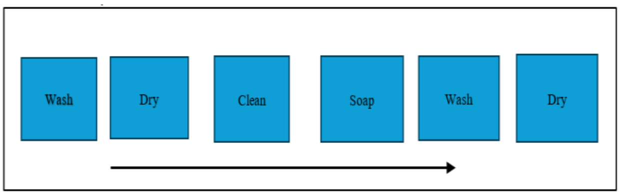

Figure 1. Demonstrates the steps necessary for cleaning the coir fiber

2.2 Materials and their preparation

Local Indian sources provide the materials that are utilized to produce coir fibers. The matrix binder Thixotropic Laminating Epoxy (R246 TX) is produced by Kintex Ltd. The prevalent epoxy on the market possesses weak thermal and mechanical properties. However, this kind of resin is rigid and has a low level of reactivity. They would be cured by a process that transforms the linear epoxy resin structure into a 3D thermoset cross-linked structure to improve their properties. It has been manually layered here for easy airflow. These also provide benefits, including the ability to cure at room temperature, transparency, and reduced pressure moldability at a very low price. An agent named hardener will be added to the resin for this curing. This curing or hardening chemical for laminating is called H160, and Kinetix Ltd. produces it. This epoxy is carefully mixed at a 1:4 ratio with the appropriate hardener.

Consequently, no by-products are produced during the curing reaction, allowing for reduced temperatures and pressures during casting and laminating of this resin. Spreading mold-release powder inside the container will simplify removing the produced fiber material mixture. This release agent makes removing the formed mould composite from the container simple once it has dried. The chemical composition and mold release powder products used in this study are shown in Figure 2.

Figure 2. Indicates the chemical composition used for the project and mold-release powder for simple removal

2.3 Natural Fiber Fabrication

The alkali procedure was used to pre-treat the coir fibers gathered from coconut husks. These coir fibers have been then divided into groups according to their approximate lengths of 5, 10, and 15mm. as shown in Fig. 3. The distinguishing of these fibers was done by measuring the length of the fibers using rollers, then cutting the required length using scissors.

Figure 3. Indicating purchased coir fibers from the market and fabricated coir fibers

2.4 Material Preparation

Before reinforcing, R246TX epoxy resin along with H160 hardener are combined in a 1:4 ratio. The appropriate weight for coir fiber at 2% was then added to the polymer with a set quantity of hardener and accelerator, and the mixture was well mixed in a container. Before pouring the liquid, a powdered mold release is applied to the container's interior walls. A maximum amount of paste was put into the container to prevent voids. After that, the manufactured composites were permitted to solidify for at least 24 hours at room temperature. The sample is then taken out of the mould container.

This prepared sample was put in an oven and baked for 24 hours at 90°C. These samples are taken out and progressively cooled to room temperature after post-curing for 24 hours in an oven. Such samples are prepared for further analysis after they reach room temperature. The samples were subsequently divided into pieces measuring around 40mm* 20mm* 20mm using water jet techniques, as seen in Fig. 4.

These samples were polished for enhanced surface (top & bottom) finishing using abrasive grade sheets. Water is continuously added to the machinery to make grinding each sample easier. After rough grinding, these are polished again using a fine grinder by swapping the wheel for a finer one. The samples must be ground until they have a polished, smooth surface.

Figure 4. Displays the post-cured samples as well as the dimensional samples.

2.5 Block on ring test and Scanning Electron Microscope

The basic parts of the tribology machine are seen in Fig. 5. It is suggested that footnotes not be used. The Mostly Block on Ring test is utilized for abrasive wear testing. Dimensional samples with dimensions of 40mm*20mm*20mm are once more positioned on AISI 304 stainless steel with a hardness of 1250 HB.

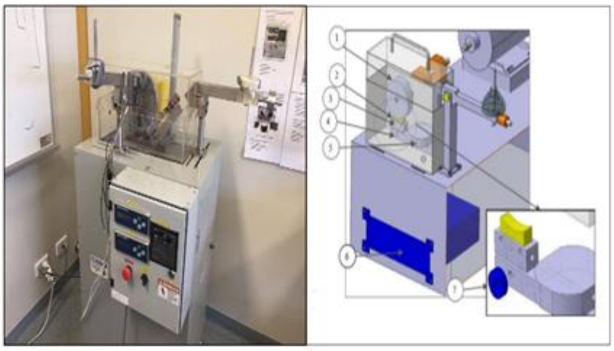

Figure 5. Tribology machine and its components: 1. Counter face, 2. sample, 3. sample holder, 4. lever, 5. load cell, 6. power supply unit, 7. ball bearing

All wear tests follow ASTM G-99 standards in a controlled laboratory setting with ambient atmospheric conditions at 20–30°C and 30–40 % relative humidity using the block-on-ring test. To avoid wear debris, entrapment, and consistent experimental technique, sufficient care should be done by carefully cleaning it with a woolen cloth after each test. Weight loss is calculated for each specimen after weighing each specimen both before & after every test.

An electronic digital balance weighing equipment with precise precision of + or - 0.00001mg calibrates weight loss. Double-sided adhesive tape is used to attach abrasive sheets with grit sizes of 400, 600, and 1200 to hardened steel discs that are 60mm in diameter. Prepared 5mm, 10mm, and 15mm specimens are set up against different grit papers (400, 600, and 1200), and a standard force is supplied to the lever mechanism.

Abrasive paper grit sizes of 400, 600, and 1200 grits, Coir fibers weight to volume percentages of 5mm, 10mm, and 15mm, sliding velocity, and typical loads (5N, 10N, 15N, 20N) are a few of the wear characteristics that are included in the wear test. The combined impact of the parameter above and the effects of each parameter individually, which are examined and graphed in this experiment, account for the wear behavior of samples. After the abrasive test, samples are examined using a SEM ("Scanning Electron Microscopy").

3. RESULTS AND DISCUSSION

The experimental findings of coir fiber-reinforced polymer composites are explained in this section. These composite experimental values' abrasive wear behavior is tabulated, and graphs are produced for their friction factor to the load and time variations. The behavior of coir fiber-reinforced polymer composites following the test was examined, the surface topologies, worn surfaces, and behavior are explained.

3.1 The Effect of The Sliding Time

Fig 6 (a-c) shows the impact of Friction wear loss on the produced coir epoxy composites for various grade sizes and periods. The friction loss v. time is shown for several periods and grades, including 0min, 2min, 4min, 6min, 8min, and 10min. The normal load applied to these samples changed the friction coefficients for coir fiber-reinforced polymer composites for distinct fiber lengths. Due to the nature of the 2-body interaction, this interphase contains the greatest number of deceiving elements, which control the formed composite's total Friction.

3.2 Friction Wear to The Sliding Time

Studying the impact of friction wear rate on the manufactured coir epoxy composites under various grade sizes and time durations is shown in Fig 7 (a-c). The friction wear versus time is shown for several periods and grades, including 0min, 2min, 4min, 6min, 8min, and 10min. It can be seen from the figs mentioned above that the coir fiber debris has a low coefficient of Friction.

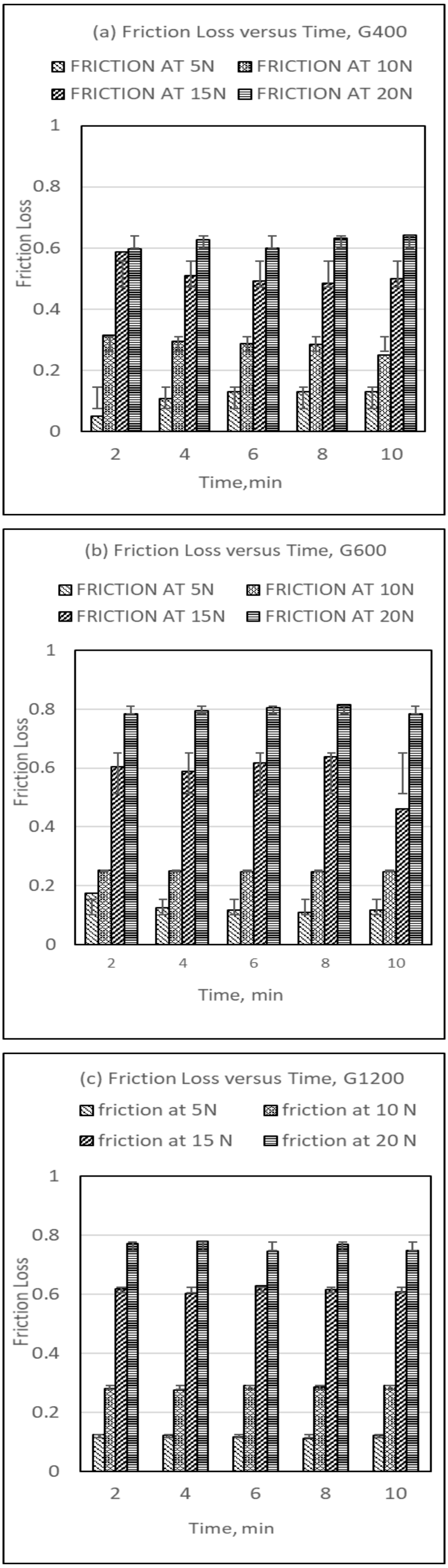

Figure 6. (a-c) Effect of sliding time to the friction los

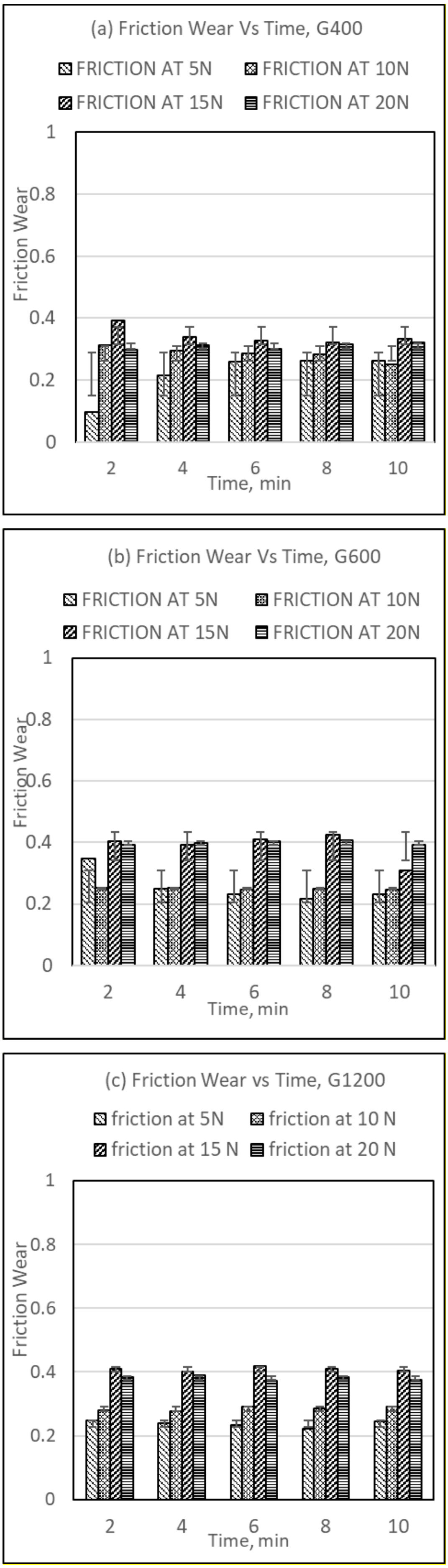

Figure 7. (a-c) Effect of sliding time to Friction wear

Because coir fibers are soft and non-abrasive and have the flexibility to deform under various typical loading situations, they are best suited for less abrasive wear, which is one reason for their low friction coefficient rate. It has also been supported by earlier literature studies that typical loading circumstances and time intervals may impact the composite's rate of frictional wear.

3.3 The Effect of The Applied Load

Fig 8 demonstrates the effects of Friction wear loss on prepared coir epoxy composites for various grade sizes & periods. The friction loss versus time is shown for several periods and grades, including 0min, 2min, 4min, 6min, 8min, and 10min. It is clear from the graphs mentioned above that frictional loss increases with an applied load increase of 20 and a grit size of 600G. A trend of a minor drop in friction coefficient and a rise in applied load by the composite may be seen from the total friction loss to the applied load. As a result, the friction loss coefficient is higher at 20N with a friction value of 0.795 for 600 grit size, but friction loss for other loads is generally lower. These findings can be contrasted with the Delamination wear" hypothesis, which is on the basis of the behavior of materials under the surface.

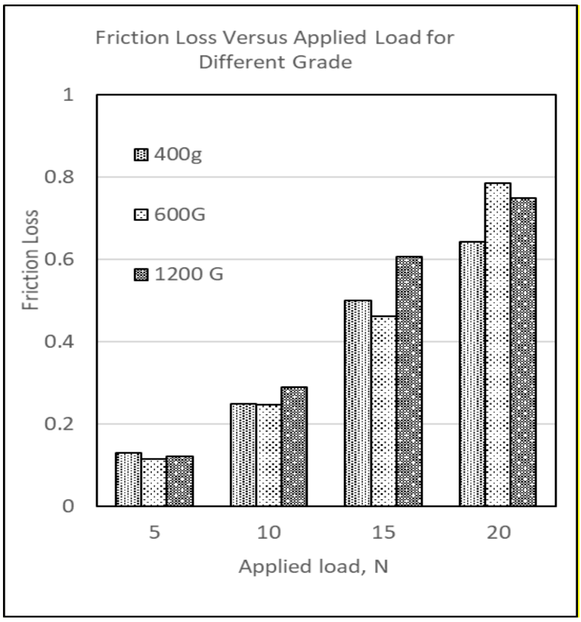

Figure 8. Demonstrates the effect of Coir Fiber Friction Loss versus Applied Load

3.4 The Effect of The SiC Grade

The size of abrasive grit impact on prepared coir epoxy composites may be evaluated by changing the abrasive grit size to the wear rate of a sample (5 mm, 10 mm, and 15 mm) for each grit size (400, 600, and 1200). Fig 9 demonstrates the association between the applied load and the wear rate for produced coir epoxy composites for various grade sizes.

The friction rate generally rises in accordance with the applied loads and chosen grades. The figs above show that friction rate has a rising tendency that varies with loads; when a material ages, repeated applied loads may constantly press the sample and cause greater frictional loss than the original rate loss. According to Charles's supporting literature, Static friction occurs when 2 surfaces don't move in relation to one another, and its coefficient of Friction varies based on the applied loads and grit sizes.

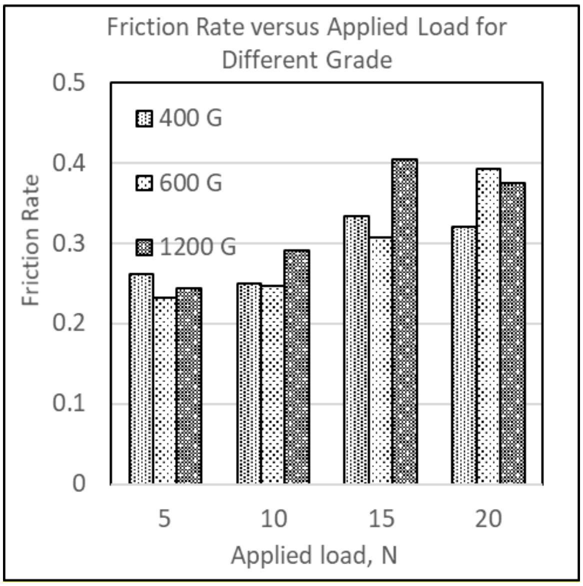

Figure 9. Graph demonstrating the influence of Coir Fiber Friction Rate Versus Applied Load

3.5 The Effect of The Fiber Length

Figs. 10(a, b) shows the impact of fiber length on the produced coir epoxy composites under various grade sizes and applied loads. The friction loss is shown for applied loads ranging from 5 to 20 N and various grades. Friction loss, as well as friction rate, fluctuated significantly for maximum as well as minimum loads of various fiber lengths. These figs show that friction loss has a higher Friction coefficient with a load of 20 N than at a load of 5 N. The friction coefficient is also rising for 5mm, 10mm, and 15mm fiber lengths of 400 and 600 grit. The strength of the interfacial connection between the fibers, which is a factor in the friction coefficient, prevents the sample from bending or breaking during testing.

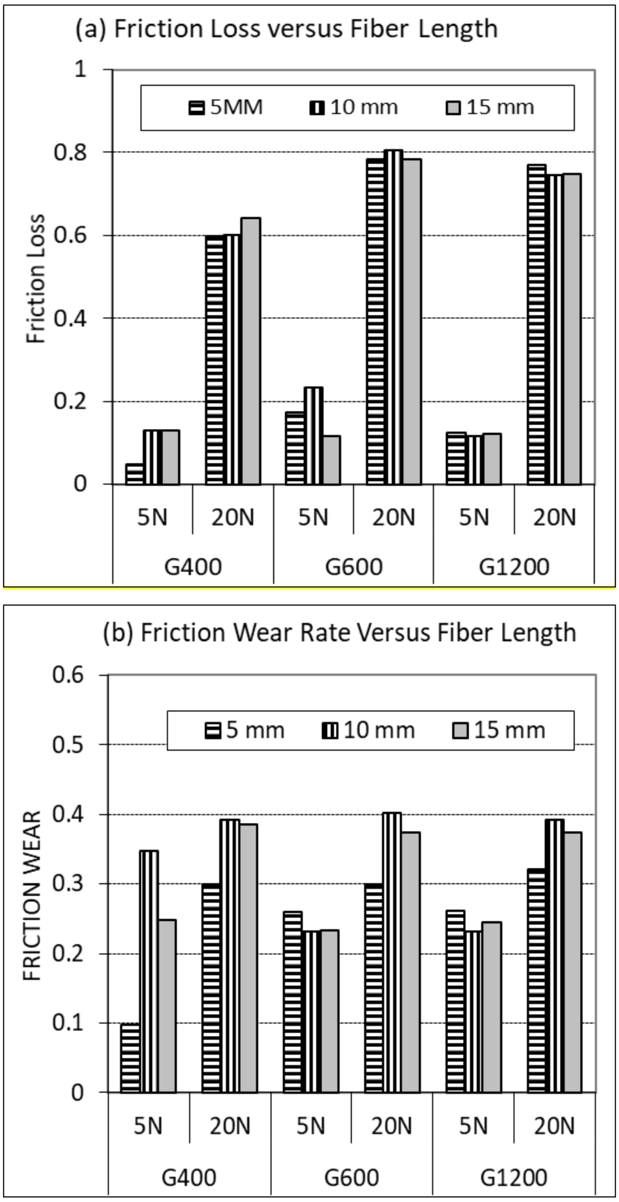

Figure 10. (a, b) Graph indicating the effect of Coir Fiber (b) Friction Wear versus Fiber Length

The friction coefficient is relatively low for a 5N applied force and a 5mm fiber length compared to other applied loads and fiber lengths. Researchers have used natural fibers like flake, hemp, and jute as reinforcements to create fiber-reinforced composites with low as well as high-strength fiber types. They discovered that the length of the fibers also affects frictional wear because the structure's internal matrix bonding makes it stronger compared to the low-length fibers. Therefore, it could be concluded from the graphs mentioned above that 15mm fiber lengths performed better than 5mm and 10mm fibers.

3.6 SEM and Optical Microscopy Observation

Images for various coir fiber lengths—5, 10, and 15 mm—and their wear loss and friction loss on coir fiber-reinforced composites are shown in Figs 11 to 13. With increasing loads, the friction coefficient for coir fiber composites with various fiber lengths (5, 10, and 15mm) is investigated. The first rise is mostly caused by mechanical surface & shear force interlocking because of the employed polymer composite. SEM micro images show some proof of micro plowing and resin wear debris.

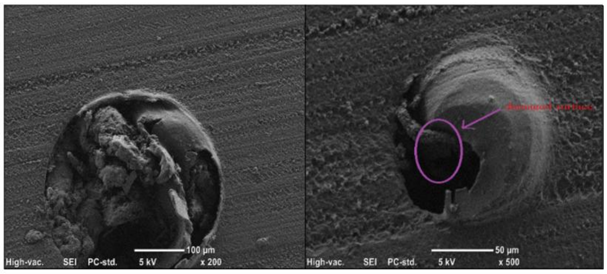

Figure 11. Images indicating after the abrasive test for 5mm fiber length

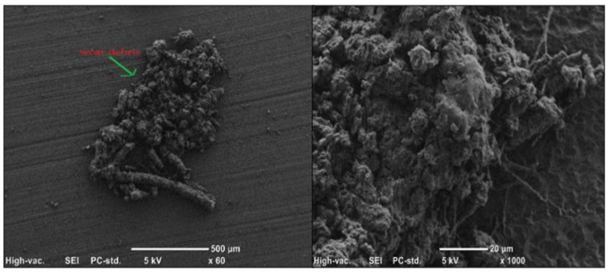

Figure 12. Images indicating after the abrasive test for 10mm fiber length

The increased wear rate, are (about) two times greater for 5mm coir fibers than 10 and 15mm fibers, is shown by the wear resistance of coir fibers with variable fiber length to the altering load. This 5mm fiber type has a low friction coefficient at a typical load of 20 N on a fiber composite. The optimal wear rate is found at 10 N, while the optimum wear loss is found at 40

N. This is caused by greater heat output from Friction at low wear rates.

SEM micrographs show that powder particles that break or slide during testing are captured at the specimen interface, and a few more passes on these mating surfaces may cause a fractured film, which may be seen via SEM images. Surface degradation to the coir fiber composite might be caused by debris obstructing the sample's surface. Comparing the SEM images, we can also see that the coir fibers have more visible cracks and voids due to applied load wear. As no evidence is seen to back up the produced photos, the surface cracks and is damaged under typical strain on coir fibers. Instead of surface degradation, SEM pictures of wear processes show certain elements such as cavities, fiber breaking, and debonding.

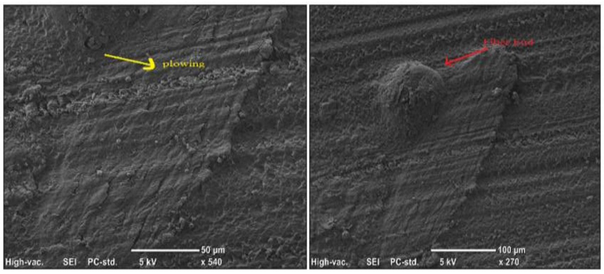

Figure 13. Images indicating after the abrasive test for 10mm fiber length

Here, the prepared sample resin begins to soften due to the rise in temperatures, which is obvious owing to frictional heating on the surface. Since there is no room for movement in a sliding mechanism, the whole force is spread throughout the fiber, causing bending without breakage along the composite fibers. We can see from the SEM images that a few lengthy fibers have been peeled off, and more micro cuts have also been found.

The holes are filled with pulverized coir material in the SEM images. Since coir fibers and resin could connect better, it was used. This improved bonding strengthens the fiber and helps the coir fiber composite resist high wear. Images taken under a microscope demonstrate resin deformation caused by changed parameters and worn surfaces. The weakest area is fiber and resin, as seen in the pictures below.
A variety of parameters are often examined, including sliding velocity of 1.9m/s, grades (400, 600, 1200), time duration (0, 2, 4, 6, 8), and fiber length (5, 10, 15mm). Previous literature assessments on various fibers indicate that mechanical forces are major causes of coir and resin deformation. Their chemical makeup, the coir fiber's characteristics, and the papers' abrasiveness impact these. The friction coefficient's main factor is the friction component, which might change owing to specimen interference or the function of the coir fiber.

4. CONCLUSION

The findings of the SEM and abrasive wear test are covered in the previous chapters, and the conclusions drawn from the findings are mentioned below.

The frictional behavior of composites is affected by coir fiber-reinforced polymer composites. Different fiber lengths may be readily synthesized into coir fiber composites, and when utilizing coir fibers compared to other threads, tri-biological features are improved for 15mm fiber length, 1200 Grit size, and applied load.

The grit sizes and fiber lengths applied under typical loads greatly influenced the wear and frictional performances. Wear rates are typically consistently high for a 5N load with a 400 Grit size and a 5mm fiber length produced composite. Additionally, applied normal load and sliding velocity significantly impacted the tri-biological characteristics of the coir fiber composite.

The shifting normal applied load causes an increase in wear rate and frictional coefficient, and grit sizes have a direct impact on the tri-biological characteristics of the produced composite. The majority of applied normal load substantially impacted wear rate and many influencing elements may also be the root of wear processes. Deeper particle size penetration on the surface during an abrasive test may result in plowing, which raises the increment rate.

The most prominent impact of wear processes is fiber material breaks. Through SEM, several features of wear and frictional behaviors may be seen, most notably Micro-cracks and wear debris on fiber composites, which are caused by the various stresses.

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REFERENCES

[1] P. Wear, "Mechanisms in polymer matrix composites abraded by bulk solids," Wear, vol. 240, pp. 207–214, 2000.
[2] R. Alajmi et al., "Study the possibility of using sisal fibers in building applications," Advanced Materials Letters, vol. 10, no. 3, pp. 222-229, 2019.
[3] International Journal of Advanced Materials Research, vol. 2, pp. 22-26, 2016.
[4] A. Shalwan, M. Alajmi, and A. Alajmi, "Effect of aging process in different solutions on kenaf fiber structure and its interfacial adhesion in epoxy composites," International Journal of Polymer Science, vol. 2018, Art. ID 1290468, 2018.
[5] I. R. A., "Influence of natural fillers on tribological and mechanical performance of polyester composites," Journal of the Egyptian Society of Tribology, vol. 13, no. 1, pp. 43-53, 2016.
[6] I. R. A., "Effect of date palm seeds on the tribological behaviour of polyester composites under different testing conditions," Journal of Materials Science and Engineering, vol. 4, no. 6, 2015.
[7] Engineering, Paper No. 38, 1985.
[8] I. R. A., "Tribological performance of polyester composites reinforced by agricultural wastes," Tribology International, vol. 90, pp. 463–466, 2015.
[9] B. A. Aldousiri, M. Shalwan, "Mechanical properties of palm fiber-reinforced recycled HDPE," Advances in Materials Science and Engineering, vol. 2013, Art. ID 508179, 2013.
[10] B. F. Yousif, "Effect of oil palm fibers volume fraction on mechanical properties of polyester composites," International Journal of Modern Physics, vol. 24, pp. 4459–4470, 2010.
[11] B. S. Aldousiri, A. Chin, "A review on tribological behaviour of polymeric composites and future reinforcements," Advances in Materials Science and Engineering, 2013.
[12] P. Wambua, J. Ivens, and I. Verpoest, "Natural fibers: Can they replace glass in fiber-reinforced plastics?" Composites Part A, vol. 63, pp. 1259–1264, 2003.
[13] S. Thomas and L. Pothan, Natural Fiber-Reinforced Polymer Composites: From Macro to Nanoscale. Philadelphia, PA, USA: Old City Publishing, 2008, pp. 3–12.
[14] B. Yousif and U. Nirmal, "Wear and frictional performance of polymeric composites aged in various solutions," Wear, vol. 272, no. 1, pp. 97-104, 2011.
[15] M. Albdiry and B. Yousif, "Morphological structures and tribological performance of unsaturated polyester-based untreated/silane-treated halloysite nanotubes," Materials & Design, vol. 48, pp. 68-76, 2013.
[16] M. D. Alexandre, "Polymer-layered silicate nanocomposites: Preparation, properties and uses of a new class of materials," 2000.
[17] P. Kiliaris and C. D. Papaspyrides, "Polymer/layered silicate (clay) nanocomposites. An overview of flame retardancy," Progress in Polymer Science, vol. 35, pp. 902–958, 2010.
[18] B. F. Yousif and N. S. El-Tayeb, "Wear characteristics of thermoset composite under high-stress three-body abrasive," Tribology International, vol. 43, pp. 2365–2371, 2010.
[19] J. W. Li, Z. Huang, C. Li, and L. Li, "Multiscale carbon nanotube-woven glass fiber-reinforced cyanate ester/epoxy composites for enhanced mechanical and thermal properties,"

Composites Science and Technology, vol. 104, pp. 81–88, 2014.
[20] A. A. Kaymakci, "Investigation of correlation between Brinell hardness and tensile strength of wood plastic composites," Composites Part B: Engineering, vol. 58, pp. 582-585, 2014.
[21] G. Fowler, P. Shipway, "The effect of particle hardness and shape when abrasive water jet milling titanium alloy Ti6Al4V," Wear, vol. 266, pp. 613–620, 2009.
[22] A. Harsha and U. Tewari, "Two-body and three-body abrasive wear behaviour of polyaryletherketone composites," Polymer Testing, vol. 22, no. 4, pp. 403-418, 2003.
[23] Y. H. Arhaim, S. Al-Taiar, and B. F. Yousif, "Correlation between frictional force, interface temperature, and specific wear rate of fiber polymer composites," Advanced Materials Research, vol. 685, pp. 45–49, 2013.
[24] H. Aireddy and S. C. Mishra, "Tribological behaviour and mechanical properties of bio-waste reinforced polymer matrix composites," Journal of Metallurgy and Materials Science, vol. 53, no. 2, pp. 139-152, 2011.
[25] K. Mylsamy, "Influence of fiber length on the wear behaviour of chopped agave americana fiber-reinforced epoxy composites," Tribology Letters, vol. 44, pp. 75–80, 2011.
[26] D. Verma, P. C. Gope, A. Shandilya, A. Gupta, and M. K. Maheshwari, "Coir fiber reinforcement and application in polymer composites: A review," Journal of Materials and Environmental Science, vol. 4, no. 2, pp. 263-276, 2013.
[27] S. A. R. Hashmi, U. K. Dwivedi, and K. Chand, "Friction and sliding wear of UHMWPE modified cotton fiber-reinforced polyester composites," Tribology Letters, vol. 21, pp. 79–87, 2006.
[28] S. Majhi, S. P. Sudhakar, and S. K. Acharya, "Tribological behavior of modified rice husk filled epoxy composite," International Journal of Scientific and Engineering Research, vol. 3, no. 6, 2012.
[29] A. Sudhakar, S. P. Majhi, and S. K. Acharya, "Tribological and mechanical properties of rice husk-filled epoxy composites," Materials Today: Proceedings, vol. 4, pp. 152–162, 2012.