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Nonlinear Analysis of Friction Behavior in Glass Fiber and Organic Clay Reinforced Polyphenylene Sulphide Composites via Pin-on Disc Testing

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Abstract:

The goal of the current study was to determine how different operating parameters, such as load, sliding speed, and sliding distance, affected the tribological behavior of composites consisting of 40% by weight of glass fiber and Polyphenylene Sulphide (PPS) with the varying percentage by weight of Bentonite clay. The study aimed to investigate the effects of different experimental settings on two distinct results: wear and coefficient of friction. This was made possible by utilizing a Taguchi L9 orthogonal array, allowing experiments to be performed at three distinct degrees of complexity. Six material samples totaling different weight percentages of bentonite clay were the subject of this investigation, which was carried out using a pin-on-disc setup as per ASTM G99. The outcome of this investigation revealed that for the virgin sample, the coefficient of friction increases with the increase in the applied average load. Also, it was observed that the rise in the average load reduced the coefficient of friction of the samples containing the Bentonite clay. Whereas an increased proportion of clay in the composite has shown a remarkable increase in the coefficient of friction value from 1% to 5%, a further rise in the clay proportion up to 7% shows a noteworthy reduction in the coefficient of friction value.

Keywords: Polyphenylene Sulphide, Glass fiber, Bentonite clay, Friction and wear, Pin on Disc, Taguchi design.

1. Introduction

In recent years, organic-inorganic nanocomposites have attracted significant attention in industry and academia. One of the most promising composites systems would be hybrids based on organic polymers and inorganic clay minerals, which belong to the general family of 2:1 layered silicates. Studies have repeatedly shown that dispersing individual high-aspect ratio silicate platelets leads to dramatic property enhancements; natural fiber composites (NFC) are becoming more and more popular for numerous for several reasons, such as their potential to more affordably and sustainably replace polymers reinforced with synthetic fibers [1] (Naidu et al. 2024). Natural fibers come in various forms, including bast, leaf, grass/reed, seed, and clay fibers. Bio-brakes have the potential to replace conventional brake material to avoid hazardous contamination. The precise behavior and impacts of each plant fiber's unique qualities and characteristics need to be investigated to improve the use of plant fiber in brake pads. Even the influence of different treatments and manufacturing processes affecting plant fiber-reinforced brake pad performance has been studied in this article [2] (Naidu et al., The ultra-high content of glass fiber fabrics influence the High-performance Polyphenylene Sulphide, a semi-crystalline thermoplastic polymer belonging to the class of advanced plastics [3] (Huang et al. 2021). Increasing interfacial layer thickness and riveting effect among GFFs effectively prevent crack propagation [4] (Zhao et al. 2019), which are the main reasons for the excellent mechanical properties of PPS composites with ultra-high content GFF filled. It is utilized as a polymer matrix for the production of composite materials. Despite its low viscosity and notable fragility, Polyphenylene sulfide (PPS) commonly displays noteworthy physical, chemical, and mechanical properties after combining various reinforcing materials. The addition of clay improves the mechanical strength of the CF/POM composite. The fillers' synergistic effect on improving Friction, wear behavior, and morphology was reported [5-6] (Hossen et al. 2016; Niu, He, and Li 2018). M.A.C. Influence of transfer film formation on Wear Behavior of Polyphenylene Sulphide Composites Reinforced with Glass/Carbon Fibers, Graphite and Polytetrafluoroethylene, by Pin-on-disc Test [7] M.AC. Besnea et al. The role of adhesive wear has also been explained [8, 11] (Mittal et al. 2015) have systematically investigated the importance of surface treatment of MMT clay and its influence on the interaction with reinforced materials, resulting in better adhesion, which consequently influences friction and wear behavior of polymer composite. They found a decrease in the value of the frictional coefficient concerning the sliding time with the decrease in frequency level, keeping the normal load constant within the observed range. At a constant frequency level, the friction coefficient decreases for a certain normal loading, and then further enhancement of the normal loading frictional coefficient increases concerning sliding time [9-10] (Carnevale, Rasool, and Bersee 2014). The tribological behavior of the carbon fiber reinforced Polyphenylene Sulphide (PPS) composite coating under dry sliding and water lubrication shows the variations of friction coefficient of the coatings with sliding time in water lubricated condition is steady than that in dry sliding. The composite coating exhibits much better wear resistance under water-lubricated conditions against stainless steel than under dry sliding [12-13] Bo. Mu et al. The mechanical and tribological properties of 70 vol % PA66/30 vol % PPS blend filled with different content of polytetrafluoroethylene (PTFE) [14] (Unal, Sen, and Mimaroglu 2004). During the investigation, it was observed that the inclusion of PTFE impairs the mechanical properties of the PA66/PPS blend. Still, simultaneously, it greatly increases the wear resistance and decreases the friction coefficient. To form the PPS composite Ecofriendly to a certain degree, a Common Mineral Bentonite Clay (Aluminum Phyllo Silicate) is mixed with PPS + 40% composite with diverse values of wt % taken after the hot compression strategy. This paper depicts the impact of '3' choosing parameters typical stack, sliding speed, sliding remove, and composition on the tribological execution of Polyphenylene Sulfide, 40% glass fiber, and characteristic Bentonite clay with diverse %by weight. Tests are tried for the coefficient of contact and wear for the sliding speed of 2.0423 m/s at the consistent stack of '20 N' and comparing variety in coefficient of contact for distinctive esteem of wt % of Bentonite clay. As far as this tribological behavior of Polyphenylene Sulfide, glass fiber, and bentonite clay is concerned, it appears that an increase inside the % by wt of clay particles and its subjective diffusing inside the PPS organize, comes around inside the accumulation, which is more slanted to the course of action of flotsam and jetsam in as a result of cement wear of composite stick surface inside the fundamental organize between the asperities on steel plate and the counter surface of composite stick carries on as grinding particle. The tribological behavior of this debris and jetsam of clay has been chosen by its relative appraise concerning the height of asperities on the counter steel plate. On the off chance that the clay debris and jetsam assess is more unmistakable than that of sick mood stature, at that point, cement speculation of pounding taken after by because it was unpleasant speculation of crushing comes into the picture comes approximately inside the decrease of coefficient of crushing regard and on the off chance that it is less than that of harshness at that point the cement speculation of pounding taken after by not because it was the unpleasant speculation of contact but in addition furrowing action of asperities on its counter surface of composite adhere comes into the picture comes around in increase in the coefficient of crushing with the earlier inspected case. Within the composite, without extension of bentonite clay, because it was the cement theory of crushing, it comes into the picture at the beginning of the sliding test taken after the furrowing of glass strands by the asperities of the counter steel plate surface. That is why the coefficient of pounding regard for the composite without clay is less than that of with clay. The degree of the debris and jetsam depends upon the accumulation of clay particles. Agglomeration plausibility increments with an increase inside the % wt of bentonite clay inside the composite because of the self-assertive diffusing of the clay particles inside the polymer cross-section. In this examination, by changing % by wt of clay particles from 1% to 5%, it has been observed that the regard of coefficient of contact is slightest for composite without clay taken after by rise when we extended it from 1% to 2% followed by diminishment inside the same from 2% to 5%.

Materials and Method

Table1. Material composition

Sr. No	Material Designation	PPS (% by Wt)	Glass Fiber (% by Wt)	Bentonite Clay (% by Wt)
1	PGB0	60	40	0
2	PGB1	59	40	1
3	PGB2	57	40	3
4	PGB3	55	40	5
5	PGB4	53	40	7

The composition of the material under consideration is shown in Table 1.

To create an eco-friendly PPS composite, a common mineral, Bentonite clay (aluminum phyllo silicate), is mixed with PPS + 40%. Wear tests were performed utilizing the DUCOM TR-20-M26 by supporting persistent contact between a stick and a turning plate. The show thinks about looking at the introduction of a round and hollow stick relative to an evenly situated plate with a distance across 300 mm and a thickness of 12 mm. The round and hollow stick has a distance across 10 mm and a stature of 40 mm, and it is arranged in an opposite way from the surface of the circle. The fabricated plates were developed utilizing a 41MoCr11 composition with hardness esteem extending from 55-58 HRC. The pins were created from steel using a composite fabric beneath thought. Before being subjected to testing, the stick and circle experienced cleaning by using a tension-activated operator. The exploration included conducting five repetitions of each test employing an unused set of sticks and plates while keeping up steady parameters. The experimentation involved conducting tests inside a dry sliding administration while keeping up encompassing temperature throughout a sliding remove of 33085.26 m. Within the consideration, three particular values for sliding speed (2.0423 m/s, 4.0846 m/s, and 6.1269 m/s) were utilized. Moreover, three one-of-a-kind levels of contact weight between the stick and plate were managed. The working test parameters with three levels are appeared in Table 2. The exploration is outlined in agreement with the 'Taguchi L9' cluster. In like manner, '9' trials per test were performed utilizing the Stick on Circle machine.

Table 2. Test parameters

Sliding speed *v* [m/s] ± 5 %	**Contact pressure *p* [N/mm^2] ± 5 %**	**Contact load *F*N [N] ± 5 %**	**Test duration [min]**
2.0423	0.25	20	30 min
4.0846	0.50	40	60 min
6.1269	0.75	60	90 min

The present study aimed to determine the coefficients of friction and wear rates of six distinct composites featuring a PPS matrix: PPS GF 40 (comprising PPS and 40% of glass fibers) with different Wt.% of Bentonite clay. D.N. Polymers in Chinchwad, Pune, produced and provided PPS composites. The research employed a precision analytical balance to weigh the specimens, pins, and discs before and after the experimental procedure. The specimens were imaged using the SEM apparatus for optical imaging to facilitate subsequent morphological analysis.

3. Results and Discussions

3.1 Influence of average load at contact surfaces on Coefficient of friction of PPS+40% GF: PGB0)

The influence of load at constant sliding speed is of concern here. Accordingly, the experiment uses the Taguchi L9 array for three influencing parameters with three levels, as shown in Table 3.

Table 3. DOE using Taguchi L_9 Array for PGB0

Sr. No	**Load (N)**	**Speed (rpm)**	**Time (min)**	**Avg. COF**
1	20	300	30	0.247
2	20	600	60	0.287
3	20	900	90	0.338
4	40	300	30	0.252
5	40	600	60	0.353
6	40	900	90	0.364
7	60	300	30	0.281
8	60	600	60	0.371
9	60	900	90	0.394

In the case of the composite PPS GF 40 (Fig. 1), the friction coefficient is generally higher than that of virgin PPS. Fundamentally, the coefficient of friction assortment within the occasion of PPS+40% GF tried at a speed of 2.0423 m/s fulfills the four known stages: increase, coming to most elevated regard, decrease, and steady state organize. It has been observed that with an increase in the contact load, the value of the coefficient of friction has been reduced, as shown in Figure 1. This can be justified as an increase in the load, which results in thermal diffusion. Consequently, the softening of the polymeric material requires less shearing force to transfer the polymer film from the pin surface to the counter surface.

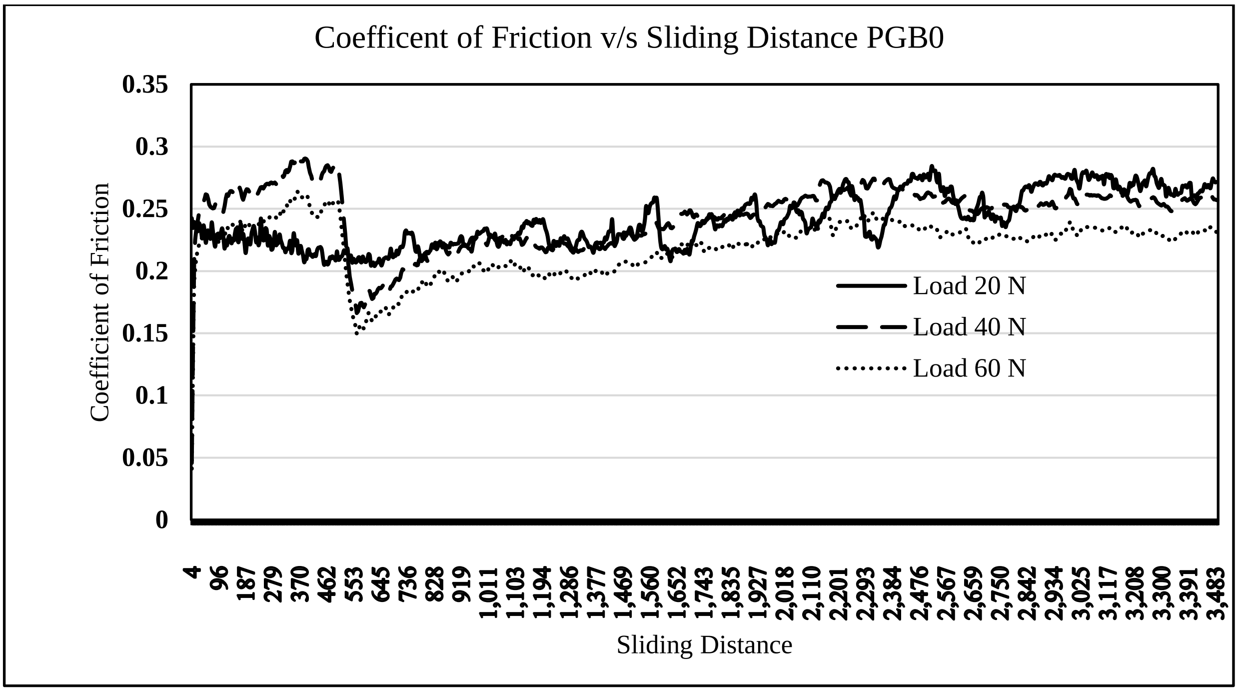


Figure 1. Coefficient of friction v/s Sliding Distance at Sliding Velocity of 2.043 m/s: PGB0

3.3 Influence of average load at contact surfaces on Coefficient of friction of PPS+40% GF+1%by wt. Bentonite Clay (PGB1)

To study the influence of varying quantities of Bentonite clay in the composite of PPS+GF 40% by wt %. The friction behavior experiment is designed to determine the COF against sliding distance for varying contact load and constant siding velocity of 2.0434 m/s, as shown in Table 4.

Table 4. DOE using Taguchi L9 Array for PGB1

Sr. No	Load(N)	Speed (rpm)	Time (min)	Avg. COF
1	20	300	30	0.332
2	20	600	60	0.378
3	20	900	90	0.387
4	40	300	30	0.285
5	40	600	60	0.328
6	40	900	90	0.355
7	60	300	30	0.263
8	60	600	60	0.289
9	60	900	90	0.312

It has been observed that the variety of coefficient of friction meets the four known stages: increment, coming to greatest esteem, diminish, and steady-state stage at all the contact loads, as shown in figure 2, which has been continued for all the remaining three samples under consideration. It has been observed that blending the composite with 1% by wt of bentonite results in an increase in the coefficient of friction value justified by the abrasive action of clay particles along with the adhesive theory of friction for the same operating conditions as compared with ‘PGB0’ which is illustrated in figure 2. However, the blend of this composite with bentonite clay decreases the coefficient of friction value with an increase in load.

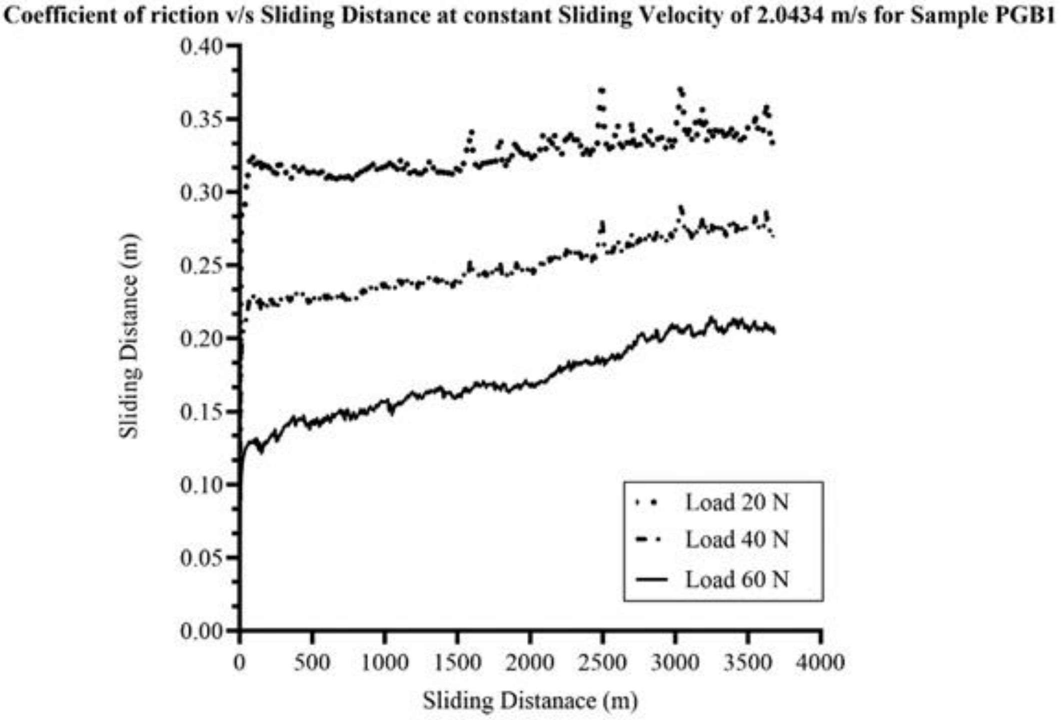


Figure 2. Coefficient of friction v/s Sliding Distance at Sliding Velocity of 2.043 m/s: PGB1

3.2 Variation of coefficient of friction concerning sliding velocity at a constant load of 20 N.

Along with investigating the influence of contact load as one of the operating parameters on the coefficient of friction, the same has been investigated for the second operating parameter, sliding speed 20 N. COF at 2.0423 m/s, 4.0846 m/s, and 6.1269 m/s Velocity level under constant average load of 20 N is plotted against the sliding distance as shown in Figure 3, which illustrates how PPS GF40 combination exhibits strong abrasive action results in an increase in the coefficient of friction with an increase in sliding speed. Variety of coefficient of friction meets the four known stages: increment, coming to greatest esteem, diminish, and steady-state stage at all the three contact loads, as shown in figure 3.

As illustrated in Figure 3, the lowest value of the coefficient of friction has been marked at a sliding speed of 2.0434 m/s and 6.1269 m/s. It shows the maximum value of the coefficient of friction.

Influence of varying proportion Bentonite clay (Aluminum Phyllosilicate) on the Friction Behavior of PPS+40% GF composite

Figure 4 exhibits the trend of the friction curve under the influence of variation in clay proportion blended with composite. From this, it has been observed that composites without blending with clay show the lowest friction coefficient. An increase in the clay % by wt first marked a rise in the value of friction coefficient till it reached 5% by wt, further showing a reduction from 5% to 7%, as shown in table 4.

Table 5. coefficient of friction value for all samples at three different load values.

Sample	Average Coefficient of Friction		
	20 N	40 N	60 N
PGB0	0.242	0.239	0.240
PGB1	0.338	0.246	0.242
PGB2	0.397	0.284	0.247
PGB3	0.368	0.282	0.220
PGB4	0.336	0.280	0.209

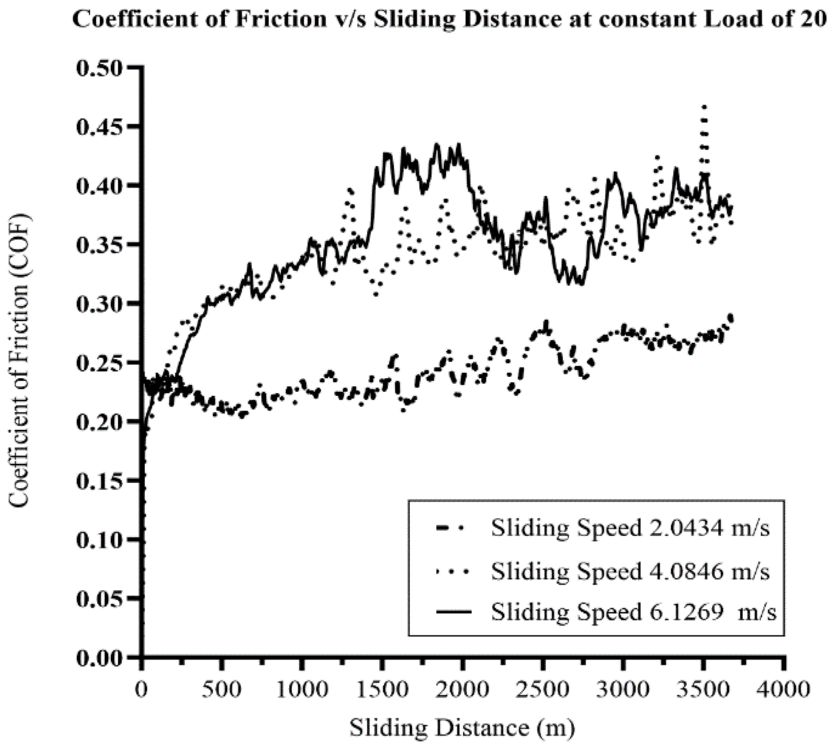


Figure 3: COF V/s Sliding Distance at a constant load of 20 N and varying sliding velocities for Sample PGB0.

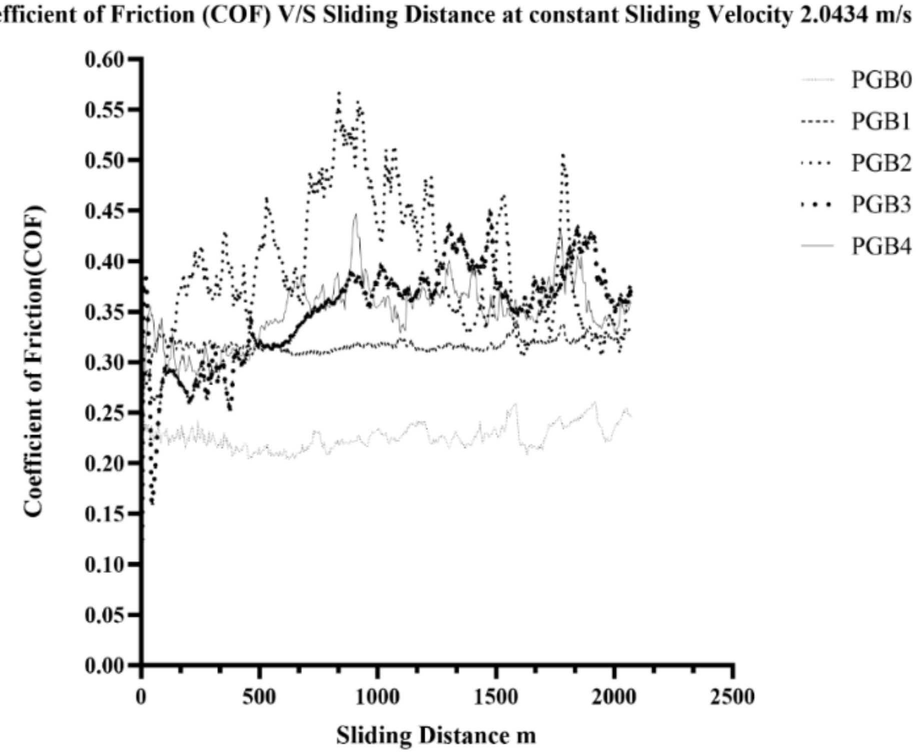


Figure 4: Coefficient of friction of PGB0, PGB1, PGB2, PGB3 and PGB4 for test speed V = 2.0423 m/s and load 20 N

From Figure 4, it has been observed that with an increase in the % by wt of Bentonite clay in the PPS and GF composite from 1% to 7%, for the first three blends, 0%,1%, and 3% of clay the coefficient of friction value has been increased and after that, for the 5% and 7% it has been reduced. However, the coefficient of friction for a 7% blend of clay is greater than that of a composite without a mix of clay. So, to avoid hazardous dust by applying brake and clutch plates, limiting the clay blend up to 3% is necessary, beyond which the blend can bear with organic clay. It has also been observed that for each blend, the value of coefficient friction reduces with the increase in the load, which helps synthesize the friction clutch and brake. This has been justified with the help of microscopic images and an energy-disruptive system, as shown in Figures 5 and 6, respectively. An increase in the value of the coefficient of friction at the beginning of the sliding test has been marked for all the test samples justified by the adhesive theory of friction along with interlocking of the asperities on the counter steel disc with the polymer pin surface followed by a reduction in the coefficient of friction value for the instant in the second stage of the sliding test due to mechanism of friction between the transferred polymer film on the counter steel disc and the polymer film surface further going with the test a slight increase in the value of the coefficient of friction has been observed due to abrasive theory of friction along with adhesive theory due to exposed glass fibers after transfer of polymer film to steel disc later on in the last stage of the test the value of coefficient of friction has been observed as stabilized value. The same scenario is exhibited for the samples with incorporated bentonite clay with abrasive friction theory due to agglomerated clay right from the beginning of the test, along with the friction theory of adhesion. This has been marked as an increase in the coefficient of friction for the composites incorporated with clay compared to the composites without clay. An increased proportion of clay in the composite creates fluctuations in the value of the coefficient of friction, which has also been marked.

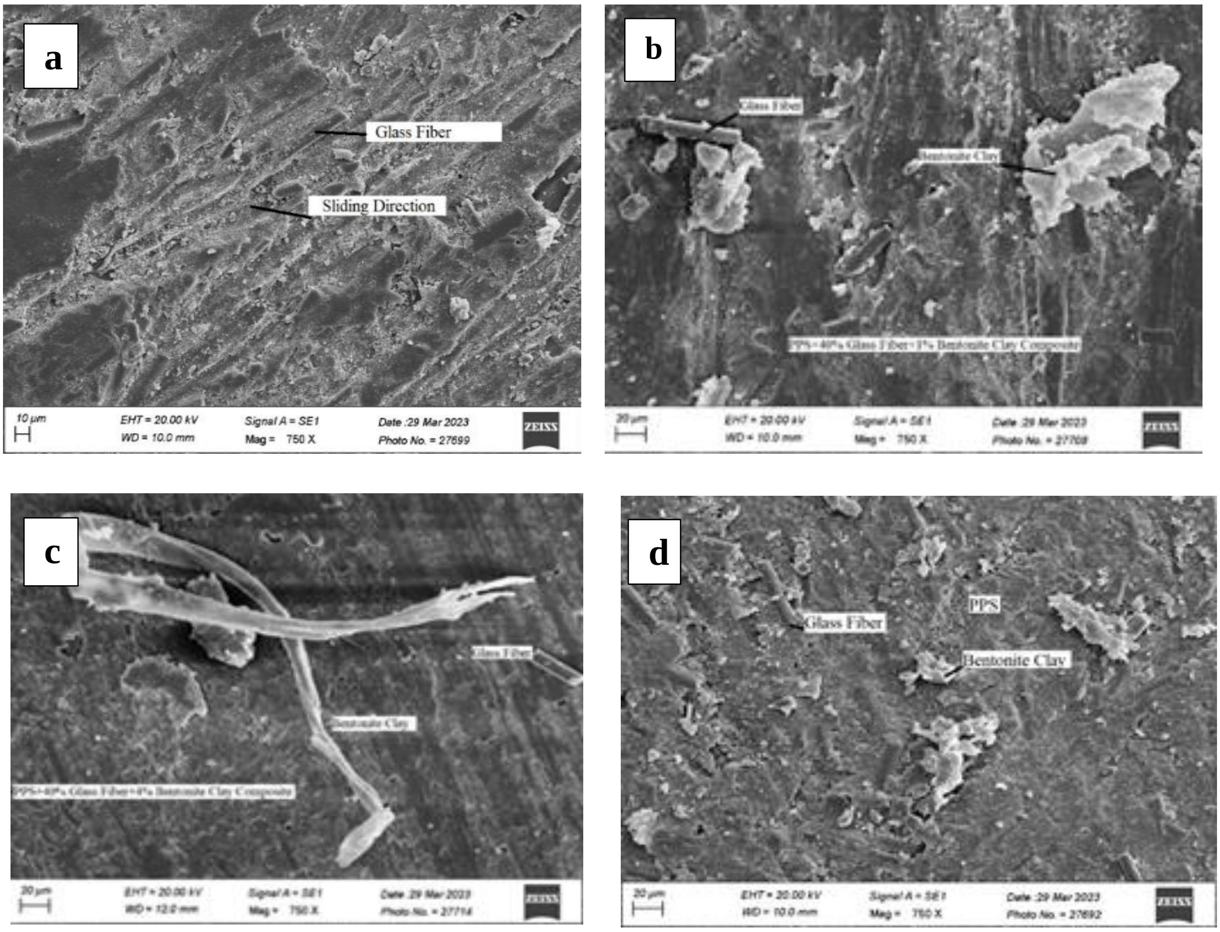


Figure 5. Optical microscopy images of the worn surface of the composite pin. (a)PGB0;(b) PGB1;(c) PGB2;(d) PGB3.

The tribological behaviour of polymers is strongly influenced by their ability to form a transfer film on the counter surface. Once a transfer film is formed, subsequent interaction occurs between polymers and transfer film of similar composition instead of polymer counter face. Therefore, studying transfer films to understand friction and wear mechanisms is essential. SEM studied the morphologies of the composite worn surfaces. Figure 5 shows the SEM pictures of the PPS+40% GF of compound blend with varying % by wt of Bentonite clay. In this composite blend, the worn surface of the composite without bentonite clay shows signs of scuffing and adhesion, which is decreased on the worn surface of the composite pin, as shown in Figure 5(a). while that of PS/40 wt % of GF/ 3% of bentonite clay shows signs of agglomerated abrasives and fatigue crack, Fig. 5b,5c, and 5d, which accounts for increased wear of the PPS composite blend with an increase in mass fraction of clay. For the transfer film formed on the counterpart, a thick and incoherent cinema can be found on the counter steel disc, corresponding to the relatively poorer wear resistance of the neat PPS+GF composite without blending with clay in the sliding against the steel. Therefore, it can be concluded that the incorporation of a relatively low fraction of Bentonite clay contributes to restraining the scuffing and adhesion of the PPS + GF composite matrix and generating transfer film of better quality on the counterpart steel surface, thus showing better wear-resistance than PPS+GF without incorporation of clay. However, a high mass fraction of Bentonite cay causes agglomerated wear and fatigue.

Elemental Analysis (EDS)

An energy dispersive Spectroscopy technique is used for the elemental analysis of the composite blend, as shown in figure 6 for PGB0, PGB1, PGB2, and PGB3 samples.

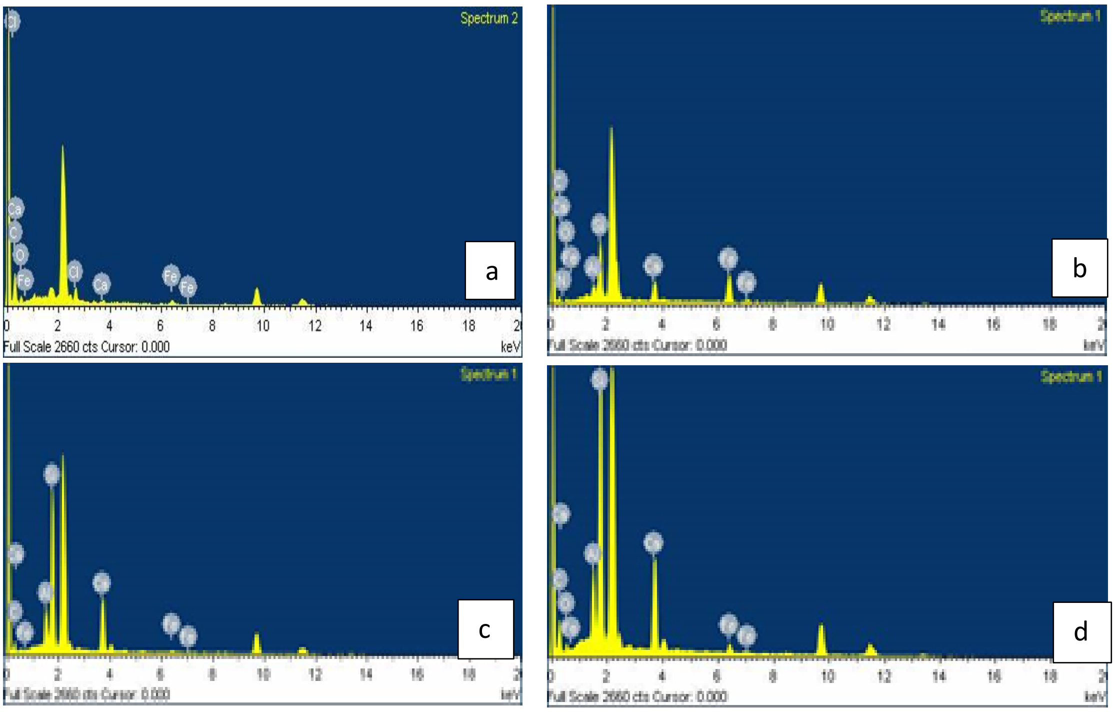
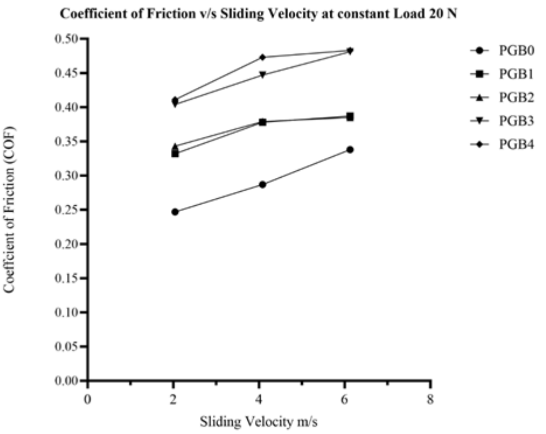


Figure 6.EDS spectrum of PGB0(a), PGB1(b), PGB2(c) and PGB3(d)

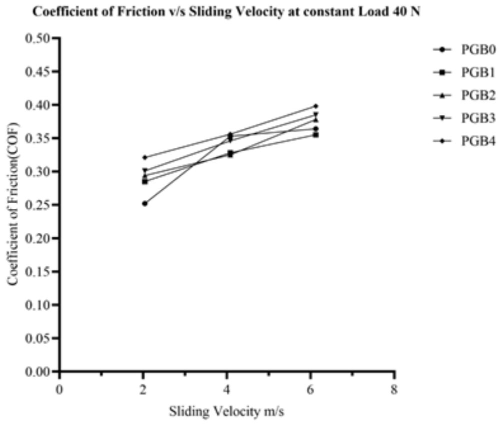
Energy dispersive spectroscopy (EDS) was used to analyze sample pin materials qualitatively. The SEM instrument is equipped with an EDS system to enable chemical analysis of the features observed in the SEM screen. In EDS, the elements observed are all identifiable: Silicon, carbon, chlorine, iron, and calcium. However, calcium and iron appear to be only trace elements, which indicates the wear of steel discs and the consequent transfer of iron to pin materials, as shown in the figure. EDS analysis of the same spectrum suggests the presence of an increasing proportion of calcium, iron, and aluminum, as shown in Figs. b, c and d are strong evidence of the presence of clay in polymer composite along with carbon and chlorine, representing PPS and glass fiber.

Influence of Sliding Velocity on Coefficient of Friction at a constant load of 20 N.

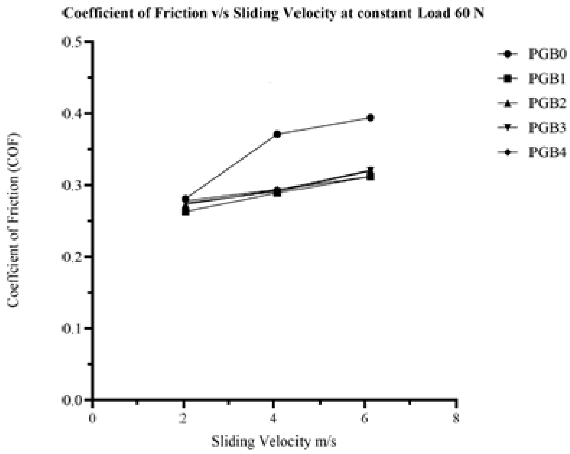
With the continuation of comparison among the '6 samples' for the friction behavior based on the different % by wt of the clay particle at constant load and speed, now proceeding towards the analysis of the influence of varying the sliding velocities on the coefficient of friction at continual load of ‘20 N’ as shown in figure 16.



a.



b



c.

Figure 7. Coefficient of friction V/s Sliding velocity at a constant load of (a)20 N, (b) 40 N, and (c) 60 N.

Individually, the variation trend in the coefficient of friction concerning the sliding velocity, as shown in Figure 7 for all the samples, shows an increase with the increase in the sliding velocity linearly, which may be due to prevalent abrasive friction rather than adhesive friction.

Influence of the load on the coefficient of friction at constant and minimum sliding velocity

As far as the design of experiments by the Taguchi method for three levels of influencing parameters Load, Speed, and Sliding Distance as a representative of the time, it is also necessary to analyze the influence of three different values of load on the coefficient of friction for all the samples under consideration at minimum sliding velocity of 2.0432 m/s. As shown in figure 8, it is observed that an increase in the 'load' results in a slight rise in the value of 'coefficient of friction' for 'PGB0' whereas the same has an effect of reduction in coefficient of friction value for samples 'PGB1', 'PGB2', 'PGB3'and 'PGB4'. It is analyzed that an increase in the load results in the rise of temperature, which consequently results in the softening of the polymer matrix, facilitating easy delamination of polymer film and further exposing the glass fibers. Exposed plowed and broken Glass fibers lock with the severities of the counter steel disc, producing the combination of both adhesion and abrasion theory of friction, increasing the coefficient of friction in 'PGB0' without any clay particles. Meanwhile, delamination is prohibited with the adhesion theory of friction in samples, including clay particles.

Even the exposed clay particles, after delayed delamination of polymer film entrapped between the mating surfaces, act as solid lubricant rather than abrasive particles as per the characteristics of the bentonite clay and result in the reduction of coefficient of friction.

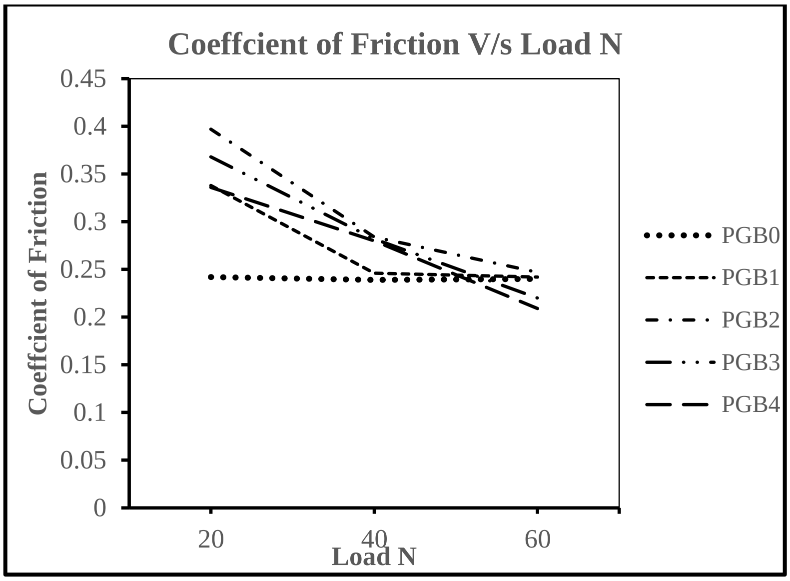


Figure 8. Coefficient of friction V/s Load N

Conclusion

The impact of the incorporation of Bentonite clay on the PPS+GF composite's friction behavior has been investigated in this work, and accordingly, the following inferences have been drawn:

The findings indicate that when the percentage of clay mass increases, the coefficient of friction first increases up to 3% and then further increases in the mass fraction of clay as it falls. A different tendency might be seen in the wear rate. A high percentage of clay in the PPS+GF composite could raise the particular wear rate and reduce the coefficient of friction. In contrast, a low percentage could help lower the wear rate and increase the coefficient of friction value. The variations in their individual surface morphologies and transfer film properties are responsible for the variations in friction and wear behaviour. As load values rise, the friction coefficient falls, and as sliding velocities rise, it increases.

Nomenclature: wt%, PGB

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REFERENCES

[1] Naidu, Mithul, Ajit Bhosale, Mahesh Gaikwad, Sachin Salunkhe, Robert Čep, and Emad Abouel Nasr. 2024. "Tribological Investigations of Hemp Reinforced NAO Brake Friction Polymer Composites with Varying Percentage of Resin Loading." *Frontiers in Materials* 11. doi:10.3389/fmats.2024.1348265.

[2] Naidu, Mithul, Ajit Bhosale, Yashwant Munde, Sachin Salunkhe, and Hussein Mohamed Abdelmoneam Hussein. 2023. “Wear and Friction Analysis of Brake Pad Material Using Natural Hemp Fibers.” *Polymers* 15(1). doi:10.3390/polym15010188.

[3] Huang, Silu, Qiuni Fu, Libo Yan, and Bohumil Kasal. 2021. “Characterization of Interfacial Properties between Fibre and Polymer Matrix in Composite Materials – A Critical Review.” *Journal of Materials Research and Technology* 13: 1441–84. doi:10.1016/j.jmrt.2021.05.076.

[4] Zhao, Liang, Yan Yu, Hao Huang, Xianze Yin, Jiashun Peng, Jiuxiao Sun, Leping Huang, Youhong Tang, and Luoxin Wang. 2019. “High-Performance Polyphenylene Sulfide Composites with Ultra-High Content of Glass Fiber Fabrics.” *Composites Part B: Engineering* 174. doi:10.1016/j.compositesb.2019.05.001.

[5] Niu, Fenglian, Runqin He, and Jian Li. 2018. “Effects of Clay and Surface Plasma-Treated Carbon Fiber on Wear Behavior of Thermoplastic POM Composites.” *Surface and Interface Analysis* 50(1): 96–100. doi:10.1002/sia.6342.

[6] Hossen, Md Faruk, Sinin Hamdan, Md Rezaur Rahman, Md Saiful Islam, Fui Kiew Liew, Josephine Chang Hui Lai, and Md Mizanur Rahman. 2016. “Effect of Clay Content on the Morphological, Thermo-Mechanical and Chemical Resistance Properties of Propionic Anhydride Treated Jute Fiber/Polyethylene/Nanoclay Nanocomposites.” *Measurement: Journal of the International Measurement Confederation* 90: 404–11. doi:10.1016/j.measurement.2016.05.006.

[7] Mittal, Garima, Vivek Dhand, Ji Il Ryu, Kyong Yop Rhee, Hyeon Ju Kim, and Dong Ho Jung. 2015. “Fabrication of Modified MMT/Glass/Vinylester Multiscale Composites and Their Mechanical Properties.” *Journal of Nanomaterials* 2015. doi:10.1155/2015/506029.

[8] Carnevale, Paola, Shafqat Rasool, and Harald E.N. Bersee. 2014. “Fibre-Matrix Interfaces in Carbon Fibre Reinforced PPS Composites: Damage Initiation and Propagation in Tensile Tests.” *Composite Interfaces* 21(4): 337–52. doi:10.1080/15685543.2014.877288.

[9] Pujan Sarkar, Nipu Modak, Prasanta Sahoo,” Reciprocating Friction and Wear Behavior of Al particulate Glass Fiber Reinforced Epoxy Composite.”, Conference Paper · December 2014., https://www.researchgate.net/publication/273950830.

[10] Jayita Bandyopadhyay, Suprakas Sinha Ray, The quantitative analysis of nano-clay dispersion in polymer nanocomposites by small angle X-ray scattering combined with electron microscopy., Polymer 51 (2010) 1437–14.

[11] Bo Mu,1,2 Qihua Wang,1 Tingmei Wang,1 Honggang Wang,1,2 Lingqi Jian1,2,” The Friction and Wear Properties of Clay Filled PA66.”, Polymer Engineering and Science—-2008, 209.

[12] Haiyan Xu, Zhizhong Feng, Jianmin Chen, Huidi Zhou, Tribological behavior of the carbon fiber reinforced polyphenylene sulfide (PPS) composite coating under dry sliding and water lubrication. Materials Science and Engineering A 416 (2006) 66–73.

[13] Unal, H., U. Sen, and A. Mimaroglu. 2004. “Dry Sliding Wear Characteristics of Some Industrial Polymers against Steel Counterface.” *Tribology International* 37(9): 727–32. doi:10.1016/j.triboint.2004.03.002.

[14] Md RH Mazumder, F Numera, A Al-Asif, and M Hasan,” Effect of bentonite clay and polypropylene matrix on the properties of silk and glass fiber-reinforced hybrid composites.” Journal of Thermoplastic Composite Materials,2002, 1–12.

[15] Zhaobin Chen, Xujun Liu, Tongsheng Li, Renguo Lu,” Mechanical and Tribological Properties of PA66/PPS Blend. II. Filled with PTFE.”, DOI 10.1002/app.22061.

[16] R. Gowtham Raj, Guddla Gayatri Tanuja, C. Labesh Kumar, Noel Anurag Prashanth Nittala, M. K. Srinath, Sherzod Shukhratovich Abdullaev, Din Bandhu,” Influence of twin-screw elements on dispersion of nano-clay in vinyl ester polymer composites using Taguchi’s orthogonal array technique.”, International Journal on Interactive Design and Manufacturing (IJIDeM) https://doi.org/10.1007/s12008-023-01492-5