Tribological Behaviour of PEEKComposite Materials Under Dry Sliding Condition

Aishwarya J. Unkule[1], Dr. S. Y. Gajjal[2], P. S. Gajjal[3]

Abstract-**In today's industrial scenario, use of dry bearing is almost becoming a routine practice. In this regard, a study on dry bearing materials was carried out. The tribological behavior of PEEK composites, including different types and amounts offiller materials was examined. Effects of operating parameters such as sliding velocity, pressure and time on tribological performance of PEEK composite materials were studied. Friction and wear tests were performed on a pin-on-disc machine, using composite pins against cast irondisc under all operating conditions. The sliding velocity and applied load plays an important role on tribological performance of PEEK composite materials by influencing the temperature of contact area. Thecoefficients of friction were found to decrease where as wear rates were found to increase with an increase in sliding velocity. It was observed that PEEK reinforced with CF, PTFE and graphite could effectively improve the tribological performance. On the basis of SEM and EDX analysis, wear mechanisms are studied.**

***Index Terms*—PEEK, carbon fiber, PTFE, graphite, Friction, Wear.**

I. INTRODUCTION

In the last few decades application of fiber reinforced polymer composites have been increasing for tribological purpose. These materials provide an alternative to metallic components because of their high mechanical and thermal performance. Tribological performance of polymer has been improved by addition of special fillers such as carbon, glass, steel fibers into matrix material.These materials are used for various components such as bearing, cams, gears, bushing and seals most of which are subjected to tribological loading conditions.

In today's industrial scenario, use of un-lubricated dry bearing is almost becoming a routine practice specially in the areas where fluids are ineffective at low or high temperature where fluids fail to survives because of environment, maintenance. In this regard, a study on dry bearing materials and their tribological performance under wide vatiry of influencing parameters such as contact pressure, sliding speed and temperatur has been carrid out.

PEEK is high performance thermoplastic polymer having outstanding mechanical as well as thermal properites at high temperature and excellent self lubricating performance.It is injection as well as compression moldable polymer with resistance to creep, abrasion and good fatigue strength. For last 15 years, it has been focous of research for improving its tribological properties in various ways. Virgin PEEK limit it's wider use because of high friction coefficient and wear rate. Therefore, PEEK is reinforced with different amount of filler materials to improve its performance.The present study consists of experimental investigation of tribological behavior of PEEK reinforced with carbon fiber, PTFE and graphite.

Based on the literature review performed, objective of this research was motivated by the fact that, so far very limited work on tribologiacal performance of PEEK composites for the dry bearing apllication has been investigated. Small laboratory specimens are generally preferred to evalute tribological performance of the materials.The present work focoused on the influence of sliding velocity and contact pressure on the friction coefficient and wear rate of PEEK composite materials.

Objective

The aim of this work is to study tribological performance of polymer composite materials for dry bearing apllication. The objectives of the present study are as follows:

1. To study the different bearing materials and select the materials for the investigation.
2. To study and select physical and mechanical parameters which influence tribological conditions such as contact pressure, sliding speed, temperature etc.along with surface conditions of mating materials.
3. To screen the performance of various fillers reinforced into base material with different amount under the all operating conditon.
4. Systematic investigation of friction and wear charactristics of materials under different operating conditions using taguchi's analysis technique on a Pin On Disc test-rig.

Literature Survey

In the present study survey is made on different bearing materials, which are generally used and their frictional and wear characteristics. The discussion further deals with the performance criteria of dry bearings including various materials currently available like different polymers and filler materials.

Lancaster [1]discussed the performance of dry bearing materials considering the effect of physical and mechanical parameters on the friction and wear of the material. Lancaster also discussed the testing of dry bearings on a customized test-rig available for monitoring the performance. The basic requirement of the dry bearing materialsis the material must be able to support an applied load under all the environment condition without distortion, deformation or loss in strength. Also both the coefficient of friction and the wear rate must be acceptably low. The properties of materials like polymers, carbon and graphite are discussed briefly along with their advantages and limitations for dry sliding bearings.

K.Friedrich, J. Karger- Kocsis, Z. Lu [2] studied the effect of temperature on the friction and wear characteristics of PEEK composites under dry sliding conditions against steel ring. A block-on-ring apparatus was used for conducting the experiments. It was observed that an increase in the testing temperature resulted in higherspecific wear rates and in lower coefficients of friction for the different materials. They also studied the performance of carbon fiber and glass fiber reinforced into PEEK. It was their conclusion that addition of carbon fiber into PEEK could produce a beneficial effect than glass fiber with respect to tribological performance.

Z. Zhang, C. Breidt, L. Chang, K. Friedrich[3] discussed the tribological performance of the PTFE and carbon fiber reinforced PEEK under sliding condition. The result showed that the most favorable range for the amount of PTFE into PEEK is 10-20% and for carbon fiber into PEEK is 15-25%.The wear rate of the PEEK composites depends on the filler materials and their mechanical properties like density, modulus etc.

Li Chang, Z. Zhang, Lin Ye, Klaus Friedrich[5]investigated the tribological properties of PEEK reinforced with carbon fiber, graphite flake, sub-micro particles of TiO_2 and ZnS under dry sliding conditions. It was observed that short carbon fiber and graphite flakes could improves the wear resistance and load carringcapacity of the base material.

G. Zhang, C. Zhang, P. Nardin, W.-Y. Li, H. Liao [6] examined the influence of sliding velocity and applied load on the friction and wear rate of virgin PEEK. It was observed that an increase of the sliding speed increases the contact temperature. This higher temperature results in softening of the matrix material. Therefore this resulted in higherspecific wear rates and in lower coefficients of friction for the different materials tested.

G. Zhang, A.K. Schlarb[7] observed the tribological parformance of PEEK composites correlated with their mechanical properties. It was their conclusion that the PEEK filled with SCF/Graphite/PTFE showsa much improved wear resistance. Apperent pressure plays an important role in wear performance. The increase in apperent pressure increases the wear rates and produces the cracing.

J. Paulo, Davim ,Rosária Cardoso [8]discussed the wear and friction performance of PEEK-CF30 and PEEK-GF30 against steel surface under dry sliding condition. It was observed that PEEK-CF30 presented the lesser friction coefficient than virgin PEEK and PEEK-GF30 which presented the higher friction coefficient throughout all sliding distance. Less wear rate observed in PEEK-CF30 and PEEK-GF3 relatively to PEEK. PEEK-CF30 presented the best tribological behavior.

G. Zhang, H. Yu, C. Zhang a, H. Liao, C. Coddet [9]studied the effect of temperature on the tribological behavior and mechanism of virgin PEEK. The temperature showed an important parameter which influenced the tribological characteristics and the crystalline structure transition of the PEEK. It was observed that before crystallization of the PEEK, the friction coefficient and wear rate increasewith increasing temperature.

II. EXPERIMENTAL DETAILS

Materials Detail:

The matrix material used in this investigation was PEEK. To improve the performance of the pure PEEK, carbon fiber, graphite and PTFE were selected as filler materials. The compositions of all these materials are listed in the table 1.All these materials were available in the form of rod from which small specimens were cut. The specimens were cut in the form of of cylindrical pin with a diameter of 9 mm and length of 30 mm. All the materials were tested against disc made from cast iron with thickness of 8mm, outer diameter of 140 mm and inside diameter of 30mm.

Table 1 Material Composition of PEEK Composites

Material	PEEK (%)	CF (%)	PTFE (%)	Graphite (%)
M1	70	30	0	0
M2	70	15	15	0
M3	70	10	10	10

Experimental Tests:

Tribological tests were carried out using Pin-On-Disc machine according to ASTM G-99. Pin-On-Disc machine is commonly used to evaluate tribological properties in the laboratories. From the literature, it is seen that the coefficient of friction and wear are dependent on speed, pressure, time etc. In this direction the study has been undertaken with all materials. Experiments were conducted under varied process parameters such as speed, pressure, time on Pin-On-disc with following specifications.

1. Pin diameter : 10 mm
2. Disc siz: 140mm, 30 mm, 8mm (OD,ID,H)
3. Disc rotation speed : 60 to 1000 rpm,
4. Sliding speed : 0.1 m/sec to 10m/sec
5. Normal load : 20 kg Maximum
6. Wear track diameter : Min. 45 mm – Max.140 mm
7. Motor : 2HP 1440(SIEMENS)
8. Hardness of the disc : 64Rc
9. Friction force :0 – 20 kg Digital read out
10. Power : 230 volt, 15 amps, 50 Hz. Ac

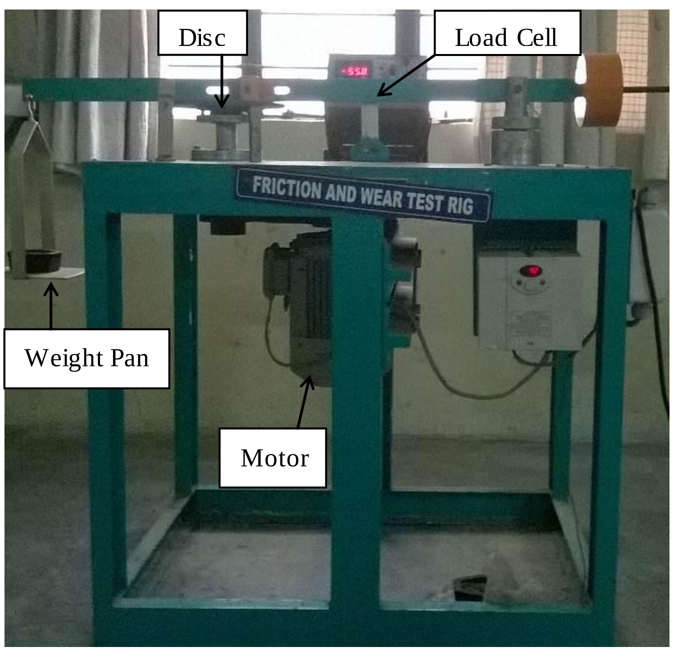

Fig. 1 Pin on Disc Machine

Fig. 1 shows the experimental set up of Pin on Disc machine. The specimen to be tested is fitted into the pin holder and pressed into contact of disc by means of lever. Specimen is loaded by lever arm and dead weight. Pin is free to slide in a direction at right angle to the axis about which the disc rotates. The beam type load cell connected to the indicator measures the frictional force. The sliding speed has been varied at different range by means of DC servomotors. The amount of wear has been measured by evaluating the difference of initial and final weight of the specimen using electronic weight balance machine.

Microscopic Analysis:

Scanning Electronic Microscopy (SEM) analysis of worn surface of all materials under investigation was carried out. Energy Dispersive X-ray (EDX) analysis was also carried out during the SEM investigation to identify the element composition in a given spectrum.

III. RESULTS AND DISCUSSION

Friction Test:

All the three materials were studied for the evaluation of coefficient of friction. From the literature it is observed that the coefficient of friction is depend on speed, pressure and time. Therefore, in this present work speed, pressure and time are selected as operating parameters under wider range. Table 2 shows the different parameters considered for the friction test and their results.

Table 2 Levels of Parameters and results of Friction Test

Sr. No	Parameters			Coefficient of Friction		
	P MPa	V m/s	T Min	M1	M2	M3
1	0.31	0.71	30	0.271	0.21	0.1807
2	0.46	0.71	30	0.2108	0.1807	0.1405
3	0.62	0.71	30	0.24	0.165	0.1506
4	0.62	0.35	30	0.23	0.1957	0.1732
5	0.62	0.71	30	0.24	0.165	0.1506
6	0.62	0.94	30	0.263	0.1807	0.1657

Experiments are carried out at all the levels of parameters. Fig.2 Shows the graph of coefficient of friction of all materials against pressure at constant sliding velocity of 0.71 m/s and time period of 30min. From the graph it has been seen that as pressure increases the coefficient of friction decreases. It was observed that with increase in the load , the temperature of the contact area also increased. Gradually increasing temperature results in decreasing the coefficient of friction.

Fig.3 represents the variation of coefficient of friction against speed for all the materials. It has been observed that as speed increases, the coefficient of friction decreases under a constant pressure of 0.62 MPa and time period of 30 min.

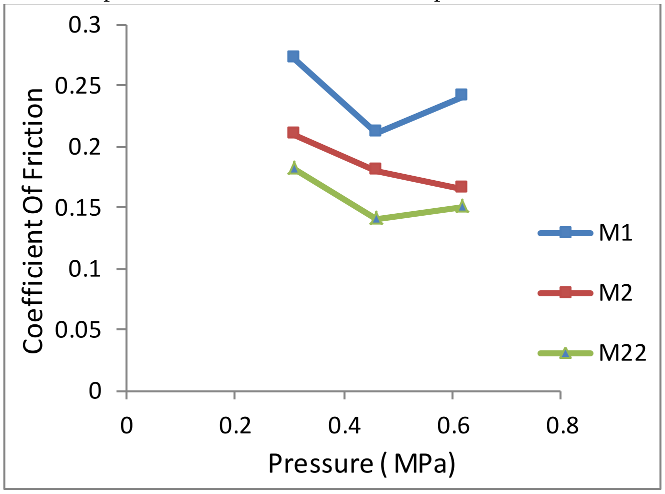

Fig.2 variation of coefficient of friction against pressure at constant velocity of 0.71m/s and time period of 30 min.

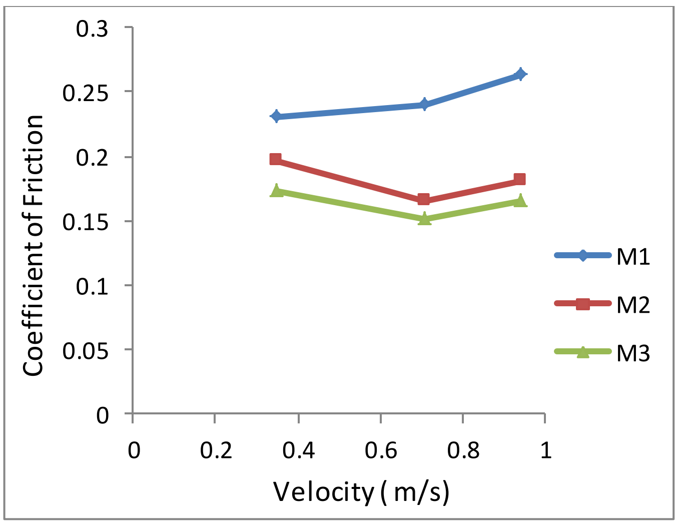

Fig. 3 variation of Coefficient of friction against sliding speed at constant pressure of 0.62 MPa and time period is 30 min.

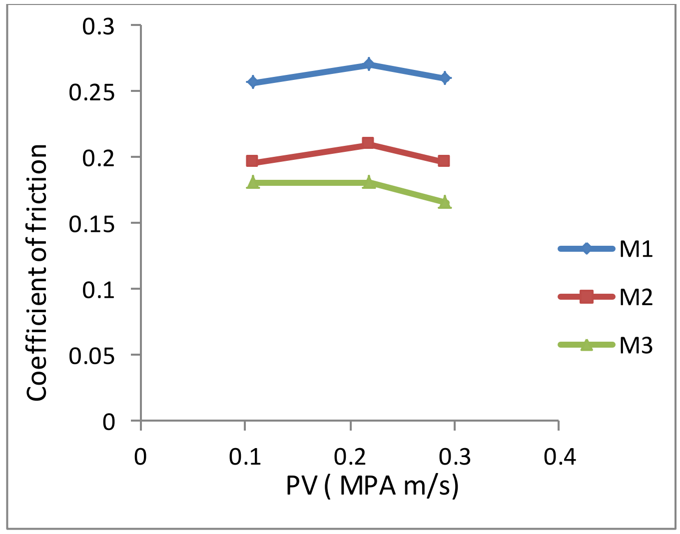

Fig.4 variation of Coefficient of Friction against PV value.

PV value also plays an important role in friction of the mating parts. Fig. 4 shows the variation of coefficient of friction against PV value. It was observed that coefficient of friction increases slightly for material filled with carbon fiber.

In the present work, it was observed that material which is reinforced with each of 10% of CF, PTFE and graphite had the lowest coefficient of friction. Material which is reinforced with 30% carbon fiber presented the highest coefficient of friction. Variation observed in the coefficient of friction is as a result of change in the temperature.

Wear Test:

When two materials are in sliding contact under pressure, wear of both materials may occur. Selection of materials is based on its ability to prevent wear. Therefore, in this study matrix material selected is PEEK which exhibits strong wear resistance. Fillers are always used to improve wear resistance properties of matrix material.

The wear characteristics of all the materials were observed under verity of parameters such as speed, pressure and time. The wear of the all materials under investigation were observed in the form of weight loss in mg. The levels of operating parameters and results of wear tests listed in table 3.

Table 3 Levels of Parametersand results of wear test

Sr. No	Parameters			Wear (mg)		
	P MPa	V m/s	T hr	M1	M2	M3
1	0.62	0.35	3	1.55	1.2	0.5
2	0.62	0.71	3	1.8	1.6	0.6
3	0.62	0.94	3	2	1.8	0.8

4	0.31	0.71	3	0.6	0.5	0.3
5	0.46	0.71	3	1.25	0.8	0.35
6	0.62	0.71	3	1.8	1.6	0.6

Fig.5 represents variation of wear against sliding speed at constant pressure of 0.62 MPa and time period of 3 hour. It has been seen that as speed increases the wear rate also increases. An increase in sliding speed leads to increase in the temperature of the contact area due to frictional heating. Thus an increase in the temperature results in an increase in contact region owing to the softening of matrix material. This could results in an increase the wear rate. Therefore it investigated that change in the wear rate occurred due to increase in temperature.

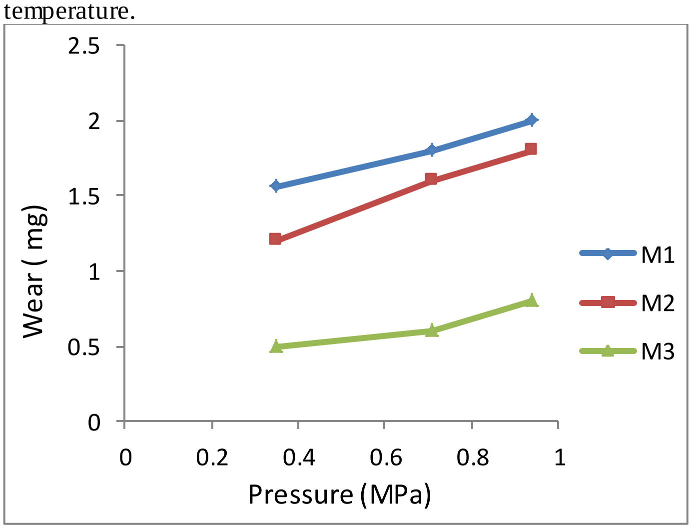

Fig.5 Variation of wear against sliding speed at constant velocity of 0.62 MPa and time of 3 hour.

Fig. 6 represents variation of wear against pressure at constant velocity of 0.71 m/s. From this graph it has been observed that the wear increases as the pressure increases for all the materials.

It was observed that PEEK reinforced with 30% carbon fiber presented the higher wear. PEEK reinforced with each of 10% of carbon fiber, PTFE and graphite showed the lesser wear rate at all operating condition. In this present study, very less variation was observed in the wear rate of material M2 and material M3. It was investigated that most favorable range of PTFE into PEEK is 10-15% and for graphite it is 10%.

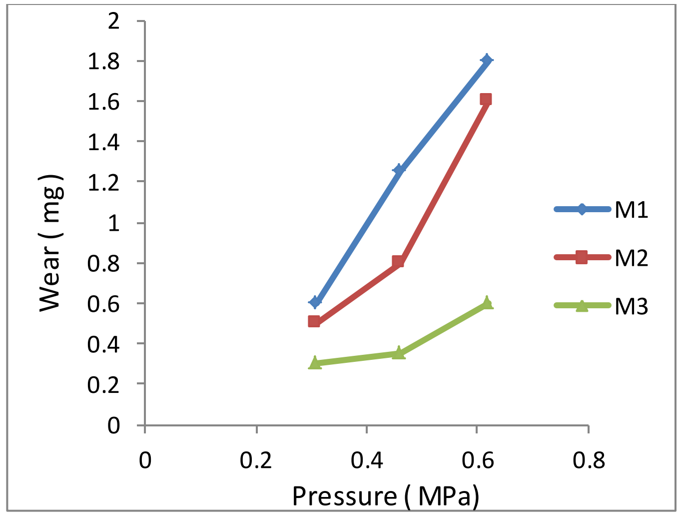

Fig. 6 variation of wear against pressure at constant velocity of 0.71m/s.

SEM and EDX Analysis:

Scanning Electron Microscopy (SEM) was carried out to analyse the worn surfaces and to examine the wear mechanism of all the materials. Fig. 7 (a) shows the SEM image of wear track of PEEK reinforced with 30% carbon fiber. SEM image clearly shows that wear occurred in the sliding direction. Fig. 7 (b) shows the worn surfaces of PEEK reinforced with 15% carbon fiber and 15 % PTFE. The removal of PEEK is interrupted by the reinforced fiber. Therefore accumulation of wear particles observed around the fiber. Fig. 8 (c) shows the SEM image of PEEK reinforced with carbon fiber, PTFE and graphite. Image clearly shows the wear track of worn surface. Because of more fillers are reinforced into matrix material, it is very complicated to analyse the wear performance. It was observed that wear particles form the contact surface collides on the other particles results in removal of material particles leads to increase in wear rate. Energy Dispersive X- ray (EDX) analysis was also carried ut during the SEM investigations. EDX is generally used to examine the chemical composition of composite materials and their effect on the performance of the materials. In the present study EDX was used to identify the elemental composition of material at various spectrums of worn surfaces. It was observed that elemental composition is different for different spectrums of same material.

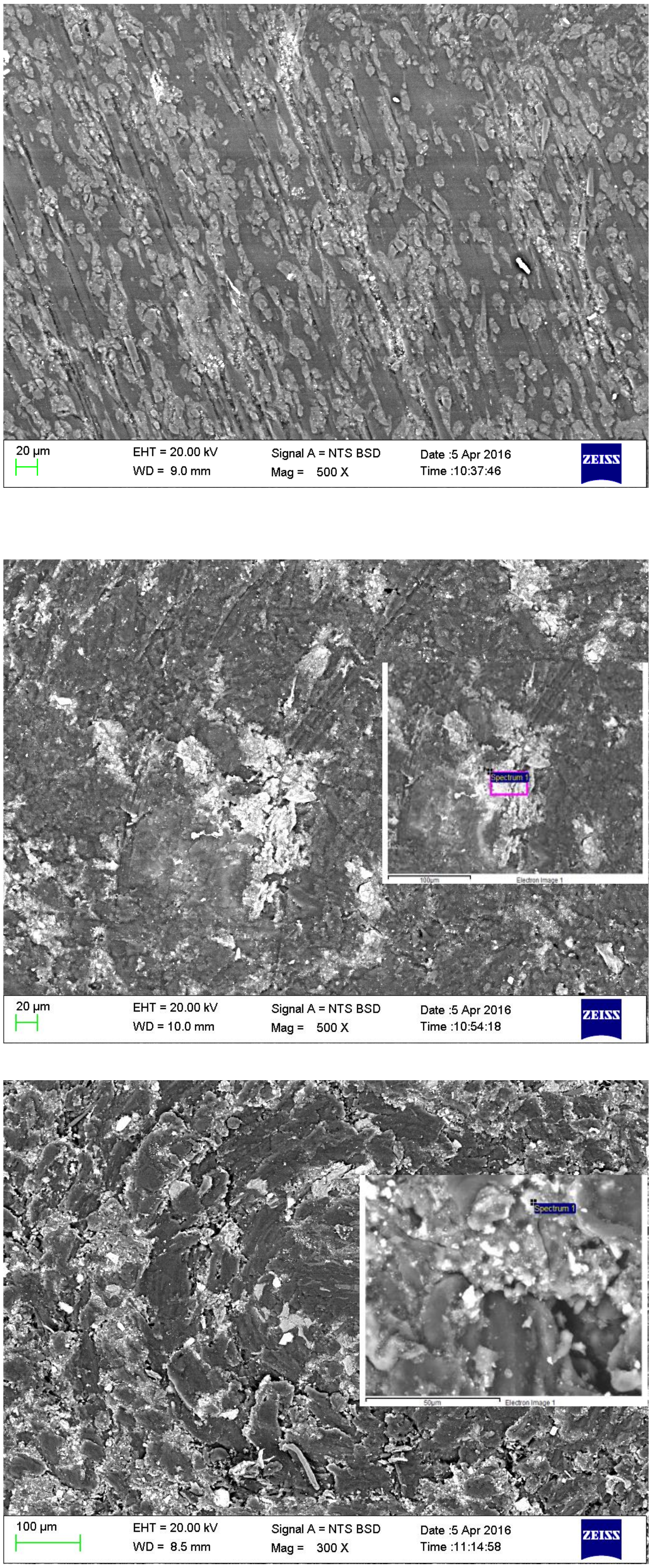

Fig. 7 SEM images of worn surface of (a) PEEK with 30% CF (b) PEEK with 15% CF and 15% PTFE (c) PEEK with 10% CF, 10% PTFE, 10% Graphite.

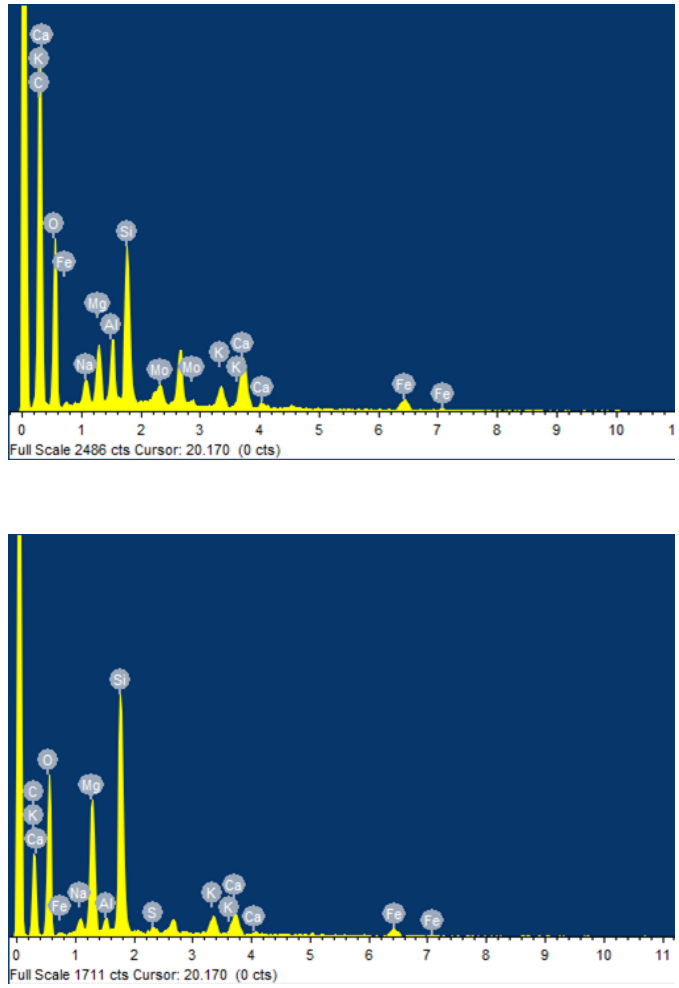

Fig. 8 EDX spectra of (a) PEEK reinforce with 15% CF and 15% PTFE (b) PEEK reinforced with 10% CF,10% PTFE, 10% graphite.

IV. CONCLUSION

In the present work, the tribological performance of PEEK composites with different amount of CF, PTFE and graphite were investigated. The effect of operating parameters such as speed, pressure and time on tribological properties were examined. The following conclusions can be drawn from study:

1. Coefficient of friction is affected by sliding speed, pressure and time. As sliding speed increases, the temperature of contact region also increases. This results in decrease in coefficient of friction for all the materials under investigation. Coefficient of friction is decreasing with respect to speed and pressure under experimental condition.
2. Wear of all materials increases with increase in speed, pressure as well as time. Increase in temperature results in softening the matrix material. Therefore wear observed is adhesive wear.
3. Reinforcement of filler fiber in matrix material has a great influence on the tribological behavior of material.

PEEK reinforced with special fillers improves the tribological properties.

4. PEEK reinforced with 10% CF, 10% PTFE , 10% Graphite presented the best material compared with other materials. It exhibited lesser friction and wear under all experimental condition.

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AUTHORS

First Author- Aishwarya .J. Unkule, PG Scholar in Mechanical Department, NBN Sinhgad School of Engineering, Ambegaon, Pune.
Email: aishwaryaunkule@gmail.com
Second Author- Prof. Dr. S. Y. Gajjal, Head of Department, Mechanical Design Engineeringdepartment, NBN Sinhgad School of Engineering, Ambegaon, Pune.
Email: shekhar.gajjal@sinhgad.edu
Third Author: Prof. Mrs. P.S. Gajjal, Assistant Professor, Mechanical department, Sinhgad College of Engineering, Vadgaon, Pune