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Investigation and Development of Tribological Behavior of PEEK and PEEK Composites under Harsh Operating Condition

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ABSTRACT

Present work describes the development and characterization of a new set of hybrid polymer composites consisting of Polyether-ether-keton (PEEK), polytetrafluoroethylene (PTFE), Bronze and MoS_2. The effects of various contact temperatures on the tribological properties of PTFE/PEEK composites were studied under dry as well as wet friction conditions. Moreover, the influence of various pressures on the friction and wear behaviors of the PTFE/PEEK composites was investigated. PEEK is a semi-crystalline polymer used as special engineering plastic due to its excellent mechanical capacity, good chemical and thermal stability. PEEK composites are often used as compressor piston rings or valve slices for their outstanding mechanical and thermal performance at high temperature conditions, where PTFE composites may fail to service. However, high friction coefficient and wear rate of pure PEEK limit its wider use many researchers found that PEEK is good in mechanical characteristic but less good performances of tribological properties. However PTFE shows better performances of tribological properties. The effect on the friction and wear behaviors of PEEK polymer composites has been improved, with addition of PTFE at room temperature. There are various operation performed in industry by different machine parts such as high pressure compressor, bearings, impeller etc. which causes wear due to heavy loading conditions and at elevated temperature. The objective of this work is to study the friction and wear properties of PEEK filled with different filler material at heavy loading conditions and at elevated temperature to enhance tribological behavior of PEEK without loss of mechanical properties.

Keywords— Composite, friction, PEEK, PTFE, wear.

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I. INTRODUCTION

In recent years various mechanical components as piston ring, Bearings etc. problems in petrochemical, process and gas industries that have occurred over the last decade on machine components, reciprocating non-lubricated compressors are examined. The majority of the oil-free compressors used in industries is of the horizontal reciprocating type and are generally found to be very reliable. The piston rings made from PTFE filled with various inorganic fillers such as carbon, glass fiber and molybdenum disulphide or combinations of these, however when the contact between sliding pairs is present there is the problem of friction and wear.For last 15 years, it has been

focus of research for enhancing its tribo-potential in various ways and review articles updating the state of art of PEEK tribology have also appeared from time. [5]

In many decades solid lubrication has been considered one of the most promising materials used to achieve better tribological properties. PEEK, PTFE these are the properties of high temperature thermoplastics can improve certain modification by or combination with other materials. PEEK is a high performance semi crystalline thermoplastic polymer, has received significant attention due to its strength and class modules properties. [6]

The effects of fillers on the mechanical and thermal properties of polymers are interrelated with those on the frictions and wear properties. Addition of Bronze increases strength and hence load carrying capacity but also increases the coefficient of friction. Some solid lubricant reduces though the load carrying capacity but also reduces the co efficient of friction. Wear properties of different materials depend on the sliding as well as on the type of material. Solid lubricant like Bronze, MoS_2improves mechanical properties it is harder, better wear, friction and chemical resistance. It is high thermal conductivity better creep resistance. [6]

The objective of the present work is to develop self-lubricating PEEK composites material for the application piston rings of compressor, bearing, impeller, etc.at room as well as at elevated temperatures. This work is helpful for dry friction and wear behavior between PEEK composite against steel in room as well as elevated temperature.

II. EXPERIMENTAL DETAILS

Materials Selected

Neat PEEK 450G fine powder with average diameter of 100 µm supplied by victrex. Polytetrafluoroethylene (PTFE) supplied by PCEE textile Kanpur, Bronze powder with 10% tin was supplied by pometon India Pvt., Mumbai, MoS_2 diameter 100 µm supplied by Vishal Pharmachem Mumbai.

The composite were prepared by compression as well as injection molding. The PEEK, PTFE, MoS_2, Bronze were mixed before melt blending on twin screen extruder in temperature range from 343°C to 400°C. Extruded strands were quenched in water followed by chopping into granules. There were dried up to 45min at 150°C for injection molding. The Sample we get in the form of bars was supplied for tribological studies.

Table.1. Specimen Composition

Specimen	Compositions (%wt.)
S1	PEEK (100)
S2	PEEK(70)+PTFE(15)+MoS_2 (15)
S3	PEEK (70) + PTFE (15)+ BRONZE (15)

Tribological studies

The prepared samples were used for tribological test for ambient as well as elevated temperature at P. Dr. V.V Patil College of EngineeringAhamednagar, Maharashtra. The wear was performed on a pin-on disc apparatus according to ASTM D2538 and ASTM D2396.The test rig was supplied by DUCOM Instrument Banglore, shown in fig.1. Especially the wear tests were conducted for non-lubricating reciprocating compressor piston ring.

The pin on Disc discussed elsewhere was selected for this work. The composite pin (4x4x30 mm^3) oscillated against counter face of steel EN-38 Disc with dimension 165x8mm thickness.

Fig.1: Pin on Disc test rig

The variation in the temperature of collet is in the steady sate was less than ±5°C, during the test load values were selected from ranges 10N to 80N and temperature were kept from ambient to 150°c as glass transition temperature of PEEK is 143°c and melting temperature is 343°C as per standard data supplied by Victrex. Also another aim for keeping the temperature 150°Chas taken specific application of ATLAS CAPCO non lubricating reciprocating air compressor. The generally discharge temperature of compressed air vary from ambient to 70°Cas compressor run continuously long time. Also similarly all parameter like sliding velocity, load and temperature parameter were selected on basis of considering same application.

Following are the Compressor specification and operating parameters were selected for the studies.

Table.2. Compressor specification and operating parameter

Compressor specification : MODEL: BD-NL	
Working pressure	8kgf/cm^2
Compressor speed	450 rpm to 850 rpm
Stroke length	120mm
Cylinder diameter	100mm
Operating parameter selected:	
Loads	20, 40, 80 N
Sliding velocity	1.4m/s
Temperature	Ambient & Elevated
Duration of experiment	3 hrs/specimen

Especially this test was conducted for the non-lubricated reciprocating compressor piston rings. The aim of these studies is to minimize wear rate. The load rangesselected as 20N to 80 N which is based on the application of non-lubricating air compressor having working pressure of 8kgf/cm^2. The working pressure of compressor is depends on force and area of cylinder (Area

of compressor cylinder calculated by stroke length anddiameter of cylinder).

$$P = F/A \qquad (1)$$

Where P = working pressure of compressor
F = Force or load applied.
A = Area of Cylinder.

Sliding velocity limiting range for non-lubricated compressor isselected was constant 1.4m/s.[6]Wear rate, frictional force, co-efficient of friction (μ) was recorded on the chart paper. Wear was calculated as a loss in weight of the polymer pin. Specific wear rate was calculated using following equation.

$$K = \Delta m / \rho L F_N \qquad (2)$$

Where K = specific wear rate in m^3/Nm
Δm = weight loss in kg
ρ = Density of sample in kg/m^3
F_N = the applied normal load in N

L = sliding distance in m.

III.RESULTS AND DISCUSSION

Comparative study of PEEK based composites at elevated temperature and 20N load condition

Fig.2, Fig.3 andFig.4 shows scatter diagram for wear rate, coefficient of friction and frictional force of PEEK, PEEK/PTFE/MoS_2, PEEK/PTFE/Bronze at elevated temperature and 20N load. With this comparison it is found that combination of PEEK/PTFE/MoS_2 show less wear rate 2.74 micron at the end of 3hr test duration. The coefficient of friction (0.23) and frictional force (4.61N) of PEEK/PTFE/Bronze is more stable and less as compared other combinations in case of 20N load.

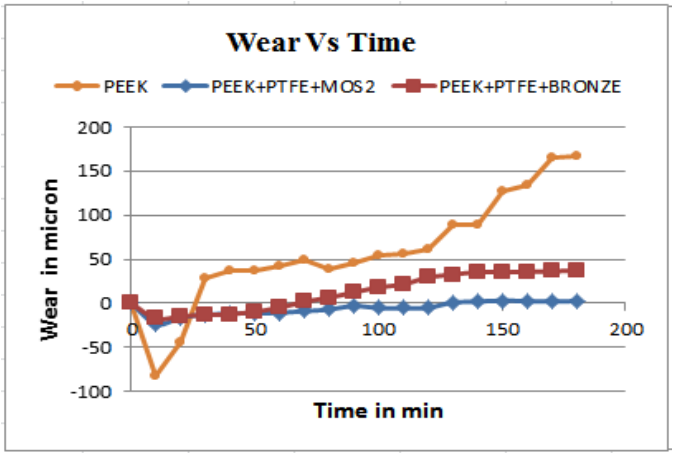

Fig.2. Wear rate of PEEK and PEEK composites at elevated temperature and 20N load

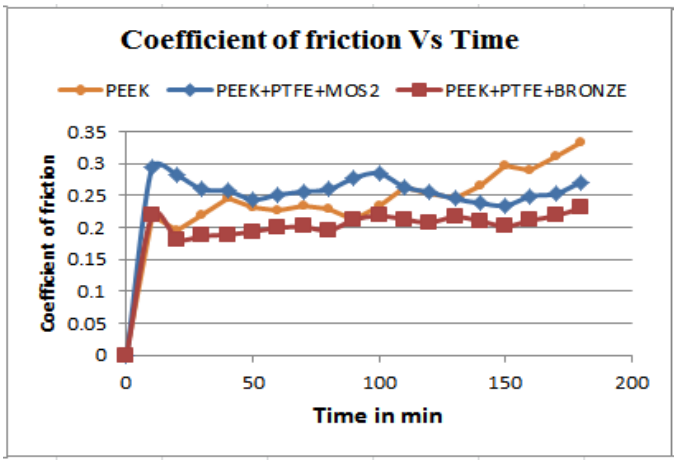

Fig.3. Coefficient of friction of PEEK and PEEK composites at elevated temperature and 20N load

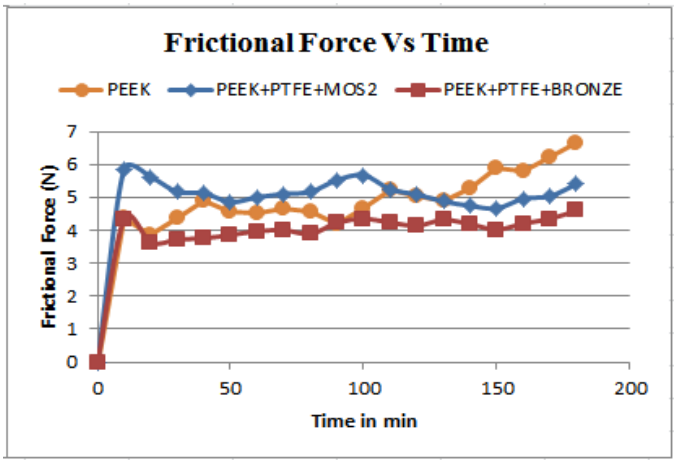

Fig.4. Frictional force of PEEK and PEEK composites at elevated temperature and 20N load

Comparative study of PEEK based composites at elevated temperature and 40N load condition

In case of 40N load and at elevated temperaturethe wear rate, coefficient of friction and frictional force showed in Fig.5, Fig.6 and Fig.7 respectively the PEEK/PTFE/MoS_2 show less wear rate 27.68 micron at the end of 3hr test duration. The coefficient of friction (0.26) and frictional force (10.58N) of PEEK/PTFE/Bronze is more stable and less as compared other combinations.

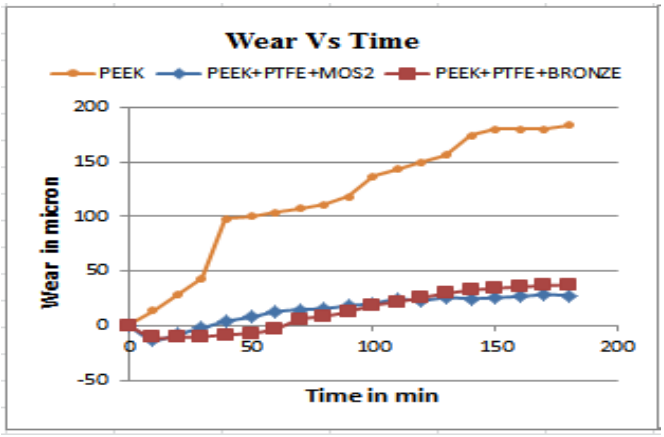

Fig.5. Wear rate of PEEK and PEEK composites at elevated temperature and 40N load

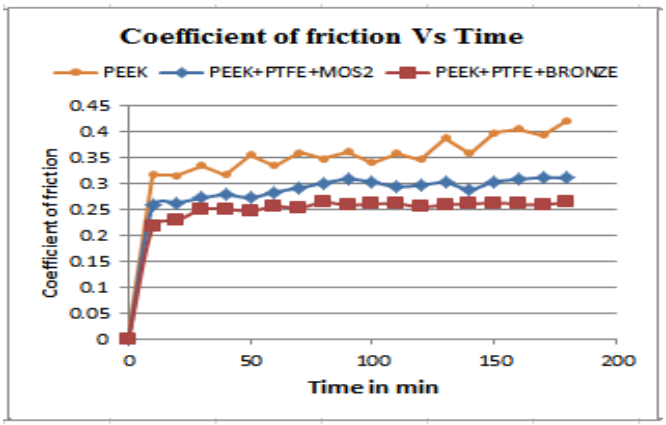

Fig.6. Coefficient of friction of PEEK and PEEK composites at elevated temperature and 40N load

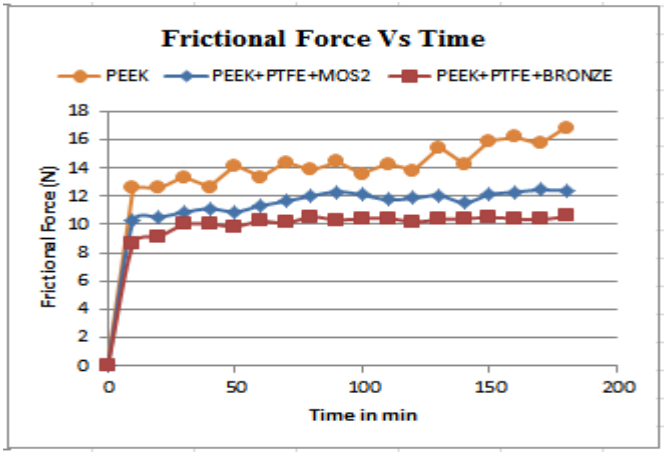

Fig.7. Frictional force of PEEK and PEEK composites at elevated temperature and 40N load

Comparative study of PEEK based composites at elevated temperature and 80N load condition

In case of harsh operating condition (80N load and at elevated temperature) the wear rate, coefficient of friction and frictional force showed in Fig.8, Fig.9 and Fig.10 the PEEK/PTFE/Bronze show less wear rate88.65 micron at the end of 3hr test duration.

Table.3. Tribological properties of PEEK and PEEK composite at harsh operating condition

Time in Min.	Wear			Coefficient Of Friction			Frictional force		
	PEEK	PEEK + PTFE + Bronze	PEEK + PTFE + MOS2	PEEK	PEEK + PTFE + Bronze	PEEK + PTFE + MOS2	PEEK	PEEK + PTFE + Bronze	PEEK + PTFE + MOS2
0	0	0	0	0	0	0	0	0	0
10	13.56	-39.55	157.61	0.312	0.245	0.274	25.02	19.65	21.97
20	27.11	-31.6	167.31	0.314	0.247	0.305	25.18	19.81	24.44
30	39.82	-20.26	168.75	0.329	0.251	0.306	26.34	20.1	24.5
40	49.52	-15.61	190.5	0.332	0.258	0.316	26.58	20.7	25.35
50	66.44	5.37	199.16	0.272	0.253	0.315	21.83	20.28	25.25
60	78.5	20.8	215.78	0.220	0.258	0.318	17.64	20.64	25.45
70	87.23	25.63	226.46	0.187	0.259	0.312	14.98	20.74	25.02
80	90.25	31.56	232.85	0.174	0.261	0.323	13.99	20.88	25.87
90	89.29	38.74	235.66	0.197	0.255	0.315	15.8	20.41	25.2
100	93.14	46.69	238.2	0.177	0.259	0.320	14.19	20.78	25.65
110	84.16	51.66	240.12	0.311	0.264	0.314	24.94	21.13	25.12
120	92.83	67.98	243.23	0.330	0.254	0.320	26.45	20.38	25.64
130	102.37	72.68	245.32	0.332	0.263	0.313	26.56	21.11	25.1
140	111.79	78.69	250.65	0.314	0.259	0.311	25.14	20.76	24.89
150	116.92	82.33	255.65	0.326	0.26	0.312	26.1	20.8	24.98
160	121.96	84.31	252.32	0.358	0.260	0.315	28.65	20.84	25.24
170	133.32	87.35	250.36	0.346	0.259	0.316	27.73	20.78	25.33
180	139.15	88.65	251.98	0.367	0.260	0.316	29.4	20.84	12.4

Also it is found that the same combination having coefficient of friction (0.26) and frictional force (20.84N) is more stable and less as compared other combinations.

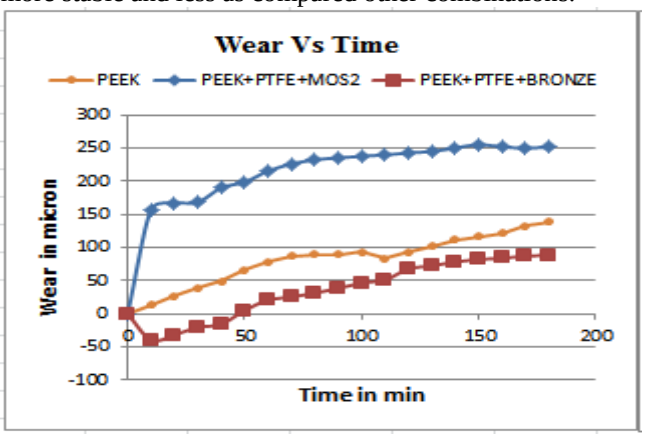

Fig.8. Wear rate of PEEK and PEEK composites at elevated temperature and 80N load

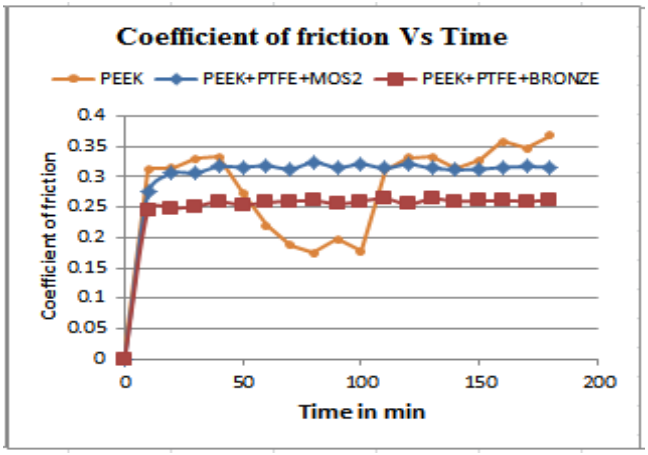

Fig.9. Coefficient of friction of PEEK and PEEK composites at elevated temperature and 80N load

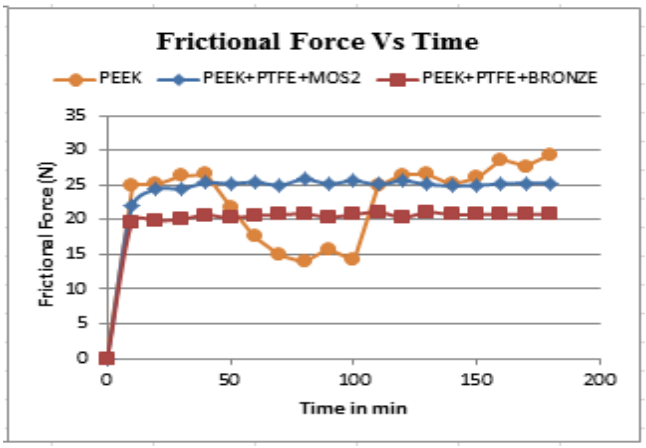

Fig.10. Frictional force of PEEK and PEEK composites at elevated temperature and 80N load

Comparative study of specific wear rate of PEEK based composites at elevated temperature

With the addition of filler material in PEEK it is found that the specific wear rate is improve. The combination of PEEK/PTFE/MoS_2 is showed less specific wear rate at low loading condition up to 40N but combination of PEEK/PTFE/Bronze showed less specific wear rate at high loading condition as 80N. Hence we can use the combination for low load and high load condition as per application requirement under elevated temperature.

Table.4.Specific wear rate of PEEK based composites at elevated temperature

Specimen	Specific wear rate (mm^3/Nm)
At elevated temperature(150°c) and 20N load	
PEEK	32×10^{-6}
PEEK+PTFE+ MoS_2	5.38×10^{-7}
PEEK+PTFE+Bronze	7.35×10^{-6}
At elevated temperature(150°c) and 40N load	
PEEK	18×10^{-6}
PEEK+PTFE+MoS_2	2.72×10^{-6}
PEEK+PTFE+Bronze	3.70×10^{-6}
At elevated temperature(150°c) and 80N load	
PEEK	6.84×10^{-6}
PEEK+PTFE+ MoS_2	12.38×10^{-6}
PEEK+PTFE+Bronze	4.35×10^{-6}

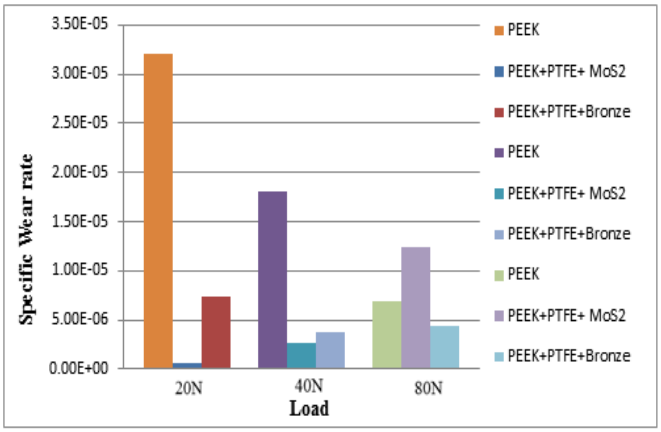

Fig.11. Effect on specific wear rate at elevated temperature &different loading Conditions

Specific wear rate of PEEK/PTFE/MoS_2 at elevated temperature and 20N,40N loads found to be$5.38 \times 10^{-7} mm^3/Nm$,$2.72 \times 10^{-6} mm^3/Nm$ respectively whichis less as compaired other combination as shown in table 4. It is also found that specific wear rate of PEEK/PTFE/Bronze is $4.35 \times 10^{-6} mm^3/Nm$is less in case of harsh operating condition (at elevated temperature and 80N load). This indicates the specific wear rate of PEEK decreased with addition 15% PTFE and 15% MoS_2 at low loading condition and with addition of 15% PTFE and 15% Bronze in PEEK indicate less specific wear rate at elevated temperature and high loading condition (harsh operating condition).

IV.CONCLUSION

Based on experimental analysis of dry friction and wear tests presented above the following conclusions were made.

1. It was found that the pure PEEK shows higher wear rate but addition of MoS_2 and Bronze enhance wear properties of PEEK.
2. It was found that the Composite PEEK/PTFE/MoS_2 exhibited low coefficient of friction and high wear resistance also shows very less specific wear rate that is 5.38×10^{-7} mm^3/Nm at ambient as well as elevated temperature and low loading condition(up to 40N load). But Composite PEEK/PTFE/Bronze exhibited low coefficient of friction and wear rate also shows less specific wear rate that is 4.28×10^{-6} mm^3/Nm at harsh operating condition.
3. MoS_2 and Bronze is widely used as solid lubricant material. These materials easily enter the roughness valley and stably stay on disk. It provides necessary lubrication during sliding. This is helpful to reduce the wear and increase wear life of component.
4. It is concluded that inorganic materials like MoS_2, bronze power as fillers could effectively prolong the wear life of transfer film of PEEK based composites.

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