Investigation and Development of Tribological Behavior of PEEK and PEEK Composites

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Abstract—Present work describes the development and characterization of a new class of hybrid polymer composites consisting of Polyether-ether-ketone (PEEK), polytetrafluoroethylene (PTFE), Bronze and MoS2. 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 ambient 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 ambient temperature to enhance tribological behavior of PEEK without loss of mechanical properties.

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

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 friction 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, MoS2 improves 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 ambient temperatures and various loading conditions. This work is helpful for dry friction and wear behavior between PEEK composite against steel at ambient temperature.

II. EXPERIMENTAL DETAILS

A. 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, M₂S₂ diameter 100 μm supplied by Vishal Pharmachem Mumbai. The composite were prepared as well as injection molding. The PEEK; PTFE, MoS₂, 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 for 44min at 150°C for injection molding. The Sample we get in the form of bars was supplied for tribological studies.

### B. Tribological studies

The prepared samples were used for tribological test for ambient temperature at P. Dr. V.V Patil College of Engineering Ahmednagar, Maharashtra. Experimentation was done on a pin-on-disc apparatus according to ASTM G99. 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 mm³) oscillated against counter face of steel EN-38 Disc with dimension 165x8mm thickness.

![Fig.1: Pin on Disc test rig](image)

The variation in the temperature of collet is in the steady state was less than ±5°C. During the test load values were selected from ranges 10N to 80N and temperature were kept ambient. Also another aim for keeping the temperature ambient has taken specific application of ATLAS CAPCO non lubricating reciprocating air compressor. The generally discharge temperature of compressed air vary from ambient to 70°C as 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 1. Specimen Composition

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Compositions (%wt.)</th>
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<tbody>
<tr>
<td>S1</td>
<td>PEEK (100%)</td>
</tr>
<tr>
<td>S2</td>
<td>PEEK(70%) + PTFE(15%) + MoS₂ (15%)</td>
</tr>
<tr>
<td>S3</td>
<td>PEEK (70%) + PTFE (15%) + BRONZE (15%)</td>
</tr>
</tbody>
</table>

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 ranges from 20 to 80 N which is based on compressor working pressure and area of cylinder. The value of contact pressure was selected with non-lubricating air compressor application which works on working pressure at 8kgf/cm². Sliding velocity is selected constant 1.4m/s. Wear rate, frictional force, coefficient 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.

\[
K = \frac{\Delta m}{\rho \cdot L \cdot F_N}\tag{1}
\]

Where
- \( K \) = specific wear rate in \( \text{m}^3/\text{Nm} \)
- \( \Delta m \) = weight loss in kg
- \( \rho \) = Density of sample in kg/m³
- \( F_N \) = the applied normal load in N
- \( L \) = sliding distance in m.

### III. RESULTS AND DISCUSSION

#### A. Comparative study of PEEK based composites at ambient temperature for 20N load

Fig.2, Fig.3 and Fig.4 show scatter diagram for wear rate, coefficient of friction and frictional force of PEEK, PEEK/PTFE/ MoS₂, PEEK/PTFE/Bronze at ambient temperature and 20N load. With this comparison it is found that combination of PEEK/PTFE/MoS₂ show less wear rate 23.94 micron at the end of 3hr test duration. The coefficient of friction (0.25) and frictional force (5.1N) of PEEK/PTFE/MoS₂ is more stable and less as compared other combinations.
B. Comparative study of PEEK based composites at ambient temperature for 40N load

In case of 40N load and at ambient temperature the wear rate, coefficient of friction and frictional force showed in Fig.5, Fig.6 and Fig.7 respectively. The PEEK/PTFE/MoS2 show less wear rate 43.98 micron at the end of 3hr test duration. The coefficient of friction (0.25) and frictional force (10.31N) of PEEK/PTFE/ MoS2 is more stable and less as compared other combinations.

C. Comparative study of PEEK based composites at ambient temperature for 80N load

In case of high loading condition (80N load and at ambient temperature) the wear rate, coefficient of friction and frictional force showed in Fig.8, Fig.9 and Fig.10 the combination of PEEK/PTFE/Bronze show very less wear rate 87.23 micron at the end of 3hr test duration as compared other
combination. Also it is found that the same combination PEEK/PTFE/Bronze having coefficient of friction (0.22) and frictional force (17.92N) is more stable and less as compared other combinations.

D. Comparative study of specific wear rate of PEEK based composites at ambient 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 at ambient temperature but combination of PEEK/PTFE/Bronze showed less specific wear rate at high loading condition as 80N at ambient temperature. With these observations it is found that the combination of PEEK/PTFE/MoS$_2$ is more suitable for low loading condition (up to 40N) at ambient temperature and the combination of PEEK/PTFE/Bronze is more suitable for high loading condition shown in fig.11.

![Fig.8. Wear rate of PEEK and PEEK composites at ambient temperature And 80N load](image)

![Fig.9. Coefficient of friction of PEEK and PEEK composites at ambient temperature and 80N load](image)

![Fig.10. Frictional force of PEEK and PEEK composites at ambient temperature and 80N load](image)

![Fig.11. Effect on specific wear rate at elevated temperature &different loading Conditions](image)

Specific wear rate of PEEK/PTFE/MoS$_2$ at ambient temperature and 20N load found to be $4.70 \times 10^{-6}$ mm$^3$/Nm is less as compared other combinations. The Specific wear rate of PEEK/PTFE/Bronze for 40N loading condition is $4.30 \times 10^{-6}$ mm$^3$/Nm which is less as compared other combinations as shown in table 4. It is also found that specific wear rate of PEEK/PTFE/Bronze at high loading condition as 80N is $4.28 \times 10^{-6}$ mm$^3$/Nm is less as compared other combinations. 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 ambient temperature and high loading 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 MoS2 and Bronze enhance wear properties of PEEK.

2. It was found that the Composite PEEK/PTFE/MoS2 exhibited low coefficient of friction and high wear resistance also shows very less specific wear rate that is 4.70x10^-6 mm^2/Nm at ambient temperature and low loading condition 20N. But Composite PEEK/PTFE/Bronze exhibited low coefficient of friction and wear rate also shows less specific wear rate that is 4.28x10^-6 mm^2/Nm at ambient temperature and high loading condition.

3. MoS2 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 MoS2, bronze power as fillers could effectively prolong the wear life of transfer film of PEEK based composites.

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