International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 5, May 2017)

Evaluation of Tribological Behavior of Peek Composites

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***Abstract*--Objective of this work is to study the effects of various contact temperatures on the tribological properties of PEEK /PTFE composites. The tribological behavior of PEEK/PTFE composite materials is change with the influence of various pressures and temperature. Polyetheretherketone (PEEK) and semi-crystalline polymers are used as special engineering plastic due to its excellent mechanical capacity, thermal and good chemical stability. PEEK composites are often used as compressor piston rings or valve slices, bearings for their outstanding mechanical and thermal performance at high temperature conditions, where polytetrafluoroethylene (PTFE) composites may fail to service. However, the high friction coefficient and wear rate of pure PEEK limit and its wider use. Also many researchers found that the PEEK is good in mechanical characteristic but have bad performances of tribological properties.**

In terms of tribological properties PTFE shows better performance. 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 at different pressure by different machine parts, which causes wear due to variation of pressure and temperature. Therefore the high wear rate at varying loading condition is a serious problem in a large number of industrial applications such as bearings, compressor piston guide rings .The study of the high-temperature tribological behavior of PEEK composites is lack. To study the friction and wear properties of PEEK filled with PTFE to enhance tribological behavior of PEEK without loss of mechanical properties with addition of suitable filler materials like Bronze.

I. INTRODUCTION

1.1. Overview of Composites

The development of composite materials and related design and manufacturing technologies are one of the most important processes in the history of materials. Composites are multifunctional materials having unprecedented mechanical, physical and tribological properties that can be used to compete the requirements of a particular application. Many composites also exhibit great resistance to high-temperature corrosion and oxidation and wear. The combination of Composites like PEEK with PTFE and Bronze has various industrial applications where tribological properties are essential at different conditions.

1.1.1. Composite Material

The Composite materials are engineering materials made up of two or more materials that remain separate and distinct on a macroscopic level while forming a single component. In practical applications two main sub types of materials are found and these are reinforcement materials and materials with matrix. The role of the matrix material is important since it provide the support to the reinforced materials. To achieve this property, the material uses the specific relative position. The reinforcements impart their special mechanical environmental damage whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc. The aim is to take advantage of superior properties of both materials without any compromising on the weakness of each other. It is only when the constituent phases have significantly different physical properties so the composite properties are different from the constituent properties.

II. PROBLEM DEFINATION & METHODOLOGY

2.1. Problem Definition

The majority of oil-free compressors used in industries is of horizontal reciprocating type and are generally found to be a very reliable. The pistons rings made up of PTFE filled with various inorganic fillers such as carbon, glass fiber and molybdenum disulphide etc, however when the contact between sliding pair occurs there is a problem of friction and wear.

2.2. Scope of The Project (Objective)

i. The basic aim of the present work is to develop and characterize a new class of composites with polyether-ether keton (PEEK) as polymer matrix and PTFE and Bronze as the reinforcing material.

ii. To Study the effect of different working conditions on PEEK and PEEK composites for

a) Wear b) coefficient of friction c) Frictional Force. d) Sliding speed e) temperature

iii Weight reduction

iv To improve mechanical properties.

v To improve life cycle of working component.

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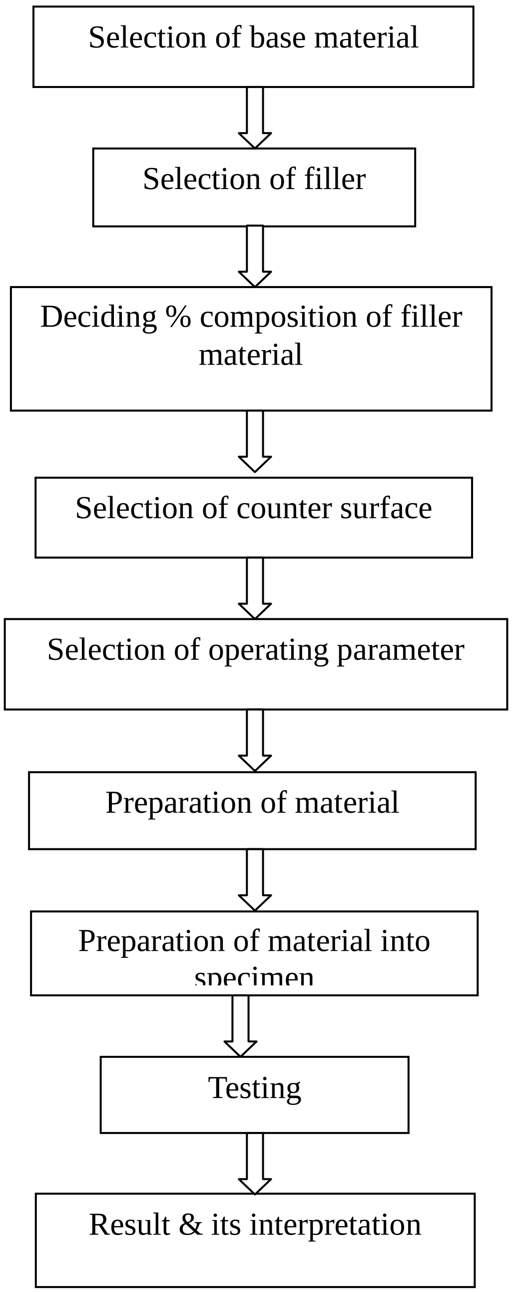
vi Experimental validation of present work by software analysis.

2.3 Methodology



III. Summary Of Literature Review

The Literature survey mentioned the best selection & combination process, blending processing temperature of PEEK and PTFE.

The work is expected to introduce a new polymer composites, Suitable for tribological applications at normal temperature also at elevated temperate and heavy loading condition. Most of researcher showed filler material percentage into base material in the range of 5 to 30%wt and most of found that filler material of 15%wt most significant it gives an effective properties and idea about best selection of composite for the particular application.

IV. Materials And Methods

This chapter describes the detail processing of the composites and the experimental procedures for characteristics and tribological evaluation. The raw materials used in this work are

1. Polyether-ether-keton (PEEK)
2. Polytetrafluroethylene (PTFE)
3. Bronze
4. Molybdenum Disulfide

V. Processing Of The Composites

5.1.1. Specimen preparation

The following grade of composites material used for specimen preparation from following source.

1. PEEK , PTFE Powder from PCEE Textile stores (Kanpur ,India)
2. BRONZE powder from Pometon India Pvt Ltd Pune.
3. Disc of diameter 165mm gray cast iron prepared at Vishal engineering limited Nasik

Commercially available polyether ether keton (PEEK) of grade 450G Fine powder with the average diameter of 100µm,thepolytetrafluroethylene(PTFE) powder with the diameter smaller than 60µm was provided by PCEE textile Kanpur, bronze powder supplied by Pometon india ltd Pune. the composite were prepared by injection molding. first PEEK, PTFE, BRONZE were mixed with different proportion for various batches with batch size 100 gm for compression molding with the proportion of PEEK,PTFE,BRONZ into it. for injection molding. for accurate weight measurement digital weighing balance is used with an accuracy of 0.0001gm for the uniform mixing that can be done by compounding of raw materials.

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Compounding by micro compounder: the specimen for mechanical testing as well as tribo-testing made by injection molding.this micro compounding facility available at CIPET Bhubaneswar. for micro compounding same all raw material like PEEK, PTFE, BRONZE weighted with digital weighing balance 15gm per batch, contains all three powder material with different percentage. in micro compounder the processing temperature for PEEK were kept at 400°c. the batch of 15gm was poured step by step and allows melting 30 minute so that complete homogeneous mixture would be formed. during processing of mixture the processing temperature are kept 400°c.this temperature are divided into six temperature zone. the temperature profile were kept 390°c,350°c,341°c front side and 340°c , 350°c,392°c for rear side for proper mixing and melting step by step. the maximum axial torque or axial forces are selected up to 8000N.for processing of PEEK material maximum force value were required 4037N.this force value increasing in ascending order from top side to the molten mixture were collected in gun which is also maintain at processing temperature 400°c in order to prevent hardening of PEEK material as its socking period is very small. To make the sample ready for application and before that for testing regarding tribology, the die molding of sample carried. The size of pins are kept within dimension of 6.0 X 6.0 X 30.0 mm. These samples were grinded for surface finishing on fine grinder as well as various fine grade emery papers were used for perfect flat surface so that zero clearance were maintained between pin and disc. in such a way 03 pins with code C1, C2&C3 were ready for testing on Tribo meter TR-20.for elevated temperature test.

5.1.2 Sample preparation for Wear Test Disc

The disc is selected with consideration of application like air compressor .the generally the cylinder liner for air compressor or cylinder is made up by stainless steel or grey cast iron with this reference the counterparts also selected as made up of same material. so the disc material was selected grey cast iron with dimension ø165mmx8mm thickness made ready for test.

Following specimen were prepared with the varying percentage of composition by weight namely C1,C2,C3,C4

Table 5.1
Designation of Composites

Specimen	Compositions
C1	PEEK (100%wt)
C2	PTFE (80%wt)+MOS2(20%)
C3	PEEK (70%wt) +PTFE (15%wt)+Bronze (15%wt)
C4	PEEK (60%wt) +PTFE (20%wt)+Bronze (20%wt)

5.1.3 Operatingparameters were selected for the studies.

- Loads applied:, 30,50,70 and 90N.
- Temperature and environment selected: Ambient,50^0C,100^0C,150^0C
- Sliding velocity: 1.8 to 3.4 m/s
- Frequency: 50 Hz,

5.2 Experimental Setup

The experimental set up includes all hardware and software needed to collection of all necessary data and analysis of obtained data.

The Wear and Friction Monitor TR 20 LE-PHM-400 DUCOM is as shown in figure with following specifications.

Table 5.2
Specification of friction & wear machine

Sr. No.	Parameters	Values/Remarks
1	Specimen Size	3 to 12mm diameter 25 to 30 mm length
2	Disc Size	165 mm × 8 mm thick
3	Wear Track Diameter	50 mm to 140 mm
4	Sliding Speed Range	0.5 m/s to 10 m/s
5	Normal Load	5N to 200N Max.
6	Disc Rotating Speed	200 to 2000 rpm
7	Friction Force	0 to 200 N
8	Wear Measurement Range	-2000 micrometer to 2000 micrometer
9	Temperature	Ambient to 400°C
10	Environmental & Lubrication Chamber	Top Portion Detachable for clamping the Specimen : Tests for Dry, Heated & Lubricated Conditions

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Figure 5.1 Friction Wear Monitor with Computer & Display Pannel

Friction tests are performed on this test rig. The friction test rig is totally worked according to automation method. There are four main factors which play an important role in this testing and these are loading quantity, working speed, temperature range, and wear of material. The system is fully controlled by a computer system. The test rig uses gray cast iron disc with piston ring in the form of pin of different diameter & length. Each test sample was mounted on load arm and pressed against the rotating disc. The sliding speed of rotating cast iron disc was varied from 344 to 478 rpm and the test duration was 10 minutes. The surface of the sample and disc was grounded with 320-grid sand paper before beginning the test. The normal load was varied from 30 to 120 N to achieve a constant friction force. The frictional coefficient was calculated by measuring the normal and shear forces every 5seconds over the entire duration of the test. The total wear of the samples was measured from digital readout on the display panel. The temperature sensors were used to record the temperature of the contact interface during the test and temperature was maintained with the help of controller.

VI. EXPERIMENTATION

6.1 Design of Experiments

Factorial design and linear regression techniques have been widely used in engineering analysis. These techniques consist of experiments with an objective of acquiring data in a controlled way, executing these experiments in order to obtain information about the behavior of a given process. Generally the aim of the task is to find out something which is innovative for that particular process. If there are number of parameters involved in the experiments then the area of the work is also in large scale. In that condition the nature of the work should be as per the DOE i.e. design of Experiments.

In order to find out relative importance of factors (that means which factor is more important or effective) we perform the experiments.

The following objectives are set for the experiment:

1. To detect the response affecting variable.
2. To find out the specific influential variable range, this set the nominal desired range of response.
3. To finds out the influential variable for the minimum response of variable.
4. To reduce the effect of uncontrolled variable.

6.1.1 Applications of Design of Experiment

There is a vital role of the design in the experimentation since it improves the performances of processing system. It also has extensive application in the development of new process. The goal of this experimental work is to enhance the yields of the processes, to decreases the cost and variability of the system. There are different types of experimental techniques of the design and some of these are as follows:

1. Selection of Alternatives which is in between of other two.
2. To select the appropriated response affecting factor.
3. To enhance or reduce the Response.
4. To minimize the Variation of Process.
5. To make the operation of system Automated and Robust in nature.

6.1.2 Advantages of DOE

Confounding of effects means we can't correlate product changes with product characteristics.

1. DOE helps us handle experimental error.
2. DOE helps us determine the important variables that need to be controlled.
3. DOE helps us find the unimportant variables that may not need to be controlled.
4. DOE helps us measure interactions, which is very important.

The piston ring are usually applied with nominal contact pressure range of 1 to 4MPa. The load applied on the pin is determined from this pressure as follows:

For pressure (P) = 1MPa

Load $F = \frac{\pi}{4} * d^2 * P$ (5)

$$F = \frac{\pi}{4} * 6^2 * 1$$

F = 30 N

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For pressure (P) = 1.7MPa

Load $F = \frac{\pi}{4} * d^2 * P$

$$F = \frac{\pi}{4} * 6^2 * 1.7$$

F = 50 N

For pressure (P) = 2.4MPa

Load $F = \frac{\pi}{4} * d^2 * P$

$$F = \frac{\pi}{4} * 6^2 * 2.4$$

F = 70 N

For pressure (P) = 3.1MPa

Load $F = \frac{\pi}{4} * d^2 * P$

$$F = \frac{\pi}{4} * 6^2 * 3.1$$

F = 90 N

The dry sliding tests are usually conducted at sliding speeds in the range of 1.8-3.4 m/s. The total number of revolutions can be determined from sliding speed by considering wear track diameter of 100 mm.

For sliding speed V=1.8 m/s

Sliding speed $V = \frac{\pi dn}{60000}$ (6)

$$1.8 = \frac{\pi * 100 * n}{60000}$$

n = 340 rpm

For sliding speed V=2 m/s

Sliding speed $V = \frac{\pi dn}{60000}$

$$2 = \frac{\pi * 100 * n}{60000}$$

n = 380 rpm

For sliding speed V=2.2 m/s

Sliding speed $V = \frac{\pi dn}{60000}$

$$2.2 = \frac{\pi * 100 * n}{60000}$$

n = 420 rpm

For sliding speed V=2.4 m/s

Sliding speed $V = \frac{\pi dn}{60000}$

$$2.4 = \frac{\pi * 100 * n}{60000}$$

n = 460 rpm

Temperature for the test were selected ambient to 150^0C as the glass transition temperature of PEEK as 143^0C and melting point is 343^0C also the discharge temperature of non lubricating air compressor vary from ambient to 70^0C as the compressor run for long time

6.1.3 Working Parameters and Their Levels

The table 6.1 shows the selected working parameters namely load, sliding velocity and temperature with three levels each. The experimentation will be done based on design of experiments of the selected parameters for compressor piston ring application.

Table No.6.1 Working Parameters and Their Levels

VII. CONCLUSION

- PEEK is one of the few polymers that can be considered for use as a true metal replacement for high temperature applications. As one of the first designer polymers, the superb range of properties . Initially, PEEK was considered an exotic material, but now it is an essential tool in the applications when no other material can meet the requirements
- The outstanding mechanical properties of PEEK at high temperatures make it suitable for the most demanding applications, but the high cost sometimes limits applications to those where the properties are very necessary.
- PTFE in PEEK definitely and significantly improved the performance of PEEK. The blends did not show any scuffing problems. A wear rate as low as 1×10^{-16} m^3/Nm was recorded and a 30 times improvement in wear rate and five times in friction coefficient was observed due to inclusion of PTFE as stated by previous researcher for various %wt of filler material and most of found 15%wt of filler material most significant thus this %wt of composition can be used for piston ring application for various operating parameter.
- Addition of filler material to PEEK and PTFE as stated by previous researcher causes an increase in hardness and wear resistance while the coefficient of friction is slightly affected and remains low thereby reducing the wear rate so, given composition will may suited for piston ring application

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