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Tribological Behaviour of Virgin Ptfe and Glass Filled Ptfe under Dry Sliding Conditions

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Abstract: *In this paper tribological properties of virgin, 25% glass fibre reinforced (GFR), PTFE polymers were studied under dry sliding conditions. PTFE samples were prepared by compaction moulding.*
Friction and wear experiments were run under ambient conditions in a pin-on-disc arrangement. Effects of sliding distance and load on friction and wear were investigated. Test was carried out at sliding distance of 500-, 1000-, 1500- and 2000m, under load of 5-, 10-, 20-, and 30N.
Analysis of surface morphology done by optical microscope SEM, EDX and 3-D profilometer, which proved useful for understanding wear mechanism. The results shows that, for pure PTFE and its composites used in this investigation, the friction coefficient decrease with the increase in load. The maximum reductions in wear rate and friction coefficient were obtained by reinforced PTFE +25% glass fibre. The wear rate for virgin PTFE was maximum compared to the PTFE composites. In addition, for the range of load and speeds used in this investigation, the wear rate showed very little sensitivity to test speed and large sensitivity to the applied load, particularly at high load values.
Keywords: *PTFE; Fillers; Wear; friction; AISI 440C.*

I. Introduction

In the design of piston guide rings for eco-sustainable reciprocating oil-free air compressors with good energy efficiency and low environmental impact gas turbine, goals were to minimize both friction and wear. Then designers have long had a need for stronger, wear resistant, chemically inert, corrosion resistant materials for these applications. Many PTFE and PTFE based composites are widely used for sliding couples against metals, polymers and other materials. However, where the contact is there, there is the problem of friction and wear. The friction between PTFE can be attributed to two main mechanisms, deformation and adhesion [16]. In this case, the deformation mechanism involves complete dissipation of energy in the contact area while the adhesion component is responsible for the friction of polymer and is a result of breaking of weak bonding forces between polymer chains in the bulk of the material.

The phenomenon of material transfer during sliding between metal and metal, PTFE and metal, and PTFE and PTFE is important from both the scientific and practical considerations. This is so because material transfer is the genesis of film development. The transfer film affects the friction and wears behavior of sliding pairs. The role of transfer film in PTFE –metal sliding contacts has long been realized as being responsible for the gradual transition from a transient wear behavior to steady state wear behavior. However, the role of sliding variables such as velocity, load and temperature on the transient wear behavior as well as their effect on transfer film is not clear. The development of transfer film in this state by abrasion of the softer polymeric material by the harder metal asperities is oversimplified and needs to be studied as a function of the variables involved.

In most practical systems, the contact during sliding occurs between a metal and a polymer. This is a preferred arrangement because of the incompatibility of the mating materials as well as the good heat transfer characteristics of the metallic material. In some instances, rarely though, there may be contact between two different polymers as well. In a PTFE metal system, transfer invariably occurs from polymer to metal but the direction of transfer in polymer–polymer systems is not that obvious.

As for the role of transfer films, it is widely believed that transfer films provide shielding of the soft PTFE surface from the hard metal asperities. As most polymers are self-lubricating

materials, the transfer film of polymer can act as a lubricant so that the coefficient of friction is much lower as compared to that between metal and metal, and it can further be lowered by proper lubrication. It is, however, not clear why transfer films are selectively formed and what governs the stability and thickness of these films during repetitive sliding.

There are three things that contribute to material transfer: the deformation of the surface under load, the fracture of material in the substrate and the transfer of this material to the other surface. The deformation and fracture are governed by the stress state in the contact zone which is affected by normal load, contact geometry, and the coefficient of friction. The effect of the factors such as the cohesion between transfer film layers and the adhesion between transfer film and counter face has also not been studied.

Most of the techniques used to study transfer films are qualitative. The lack of quantitative methods hinders understanding of the effect of various factors on the growth and steady state condition of the transfer film. The variables expected to affect the transfer film are sliding conditions such as velocity, load, atmosphere, and temperature; structure of the polymer in terms of backbone flexibility, side chains, pendant groups, and crystalline and mechanical topography, surface roughness, and chemical reactivity of the counter face. The presence of so many factors and the interaction among them makes the understanding of the role of these factors on transfer film very difficult. For example, the temperature rise at the interface changes the flexibility of molecules and also affects the reactivity of the counter face.

II. Methodology And Experimental Setup

2.1 Sample Preparation

2.1.1 Grinding

The unfinished sample of virgin PTFE, 25% glass filled PTFE of (30mmX10mm) discs and AISI 440C (7mmø) spherical pin was finished by using manual grinder. Different grit sizes (800, 1000, 1200 and 2000) were used to finish the sample respectively on a manual grinding machine.

2.1.2 Polishing

Sample were thus further polished using aerosol diamond spray based diamond polishing solutions on diamond paper. After initial flattening using the coarsest diamond grades the samples were polished using 6, 3, 1 and0.35 µm diamond paste.

2.2 Hardness Measurements

2.2.1 Hardness

One of the common modes of failures observed in materials is tribological failure i.e. due to wear. Wear of the materials depends upon to a large extent on the hardness of the material. Hardness is one of the most frequently measured properties of a developed material. Its value helps to characterize resistance to deformation, densification, wear and fracture. In metallurgy hardness is defined as the ability of a material to resist plastic deformation.

Macro-hardness tests (Rockwell, Brinell, and Vickers) are the most widely used methods for rapid routine hardness measurements for most of the materials. But for softer material such as plastic, rubber, polymer etc mainly shore hardness test are used.

2.2.2 Shore Hardness test

The hardness testing of plastics is most commonly measured by the Shore (Durometer) test or Rockwell hardness test. Both methods measure the resistance of the plastic toward indentation. Both scales provide an empirical hardness value that doesn't correlate to other properties or fundamental characteristics. Shore Hardness, using either the Shore A or Shore D scale, is the preferred method for rubbers/elastomers and is also commonly used for 'softer' plastics such as polyolefin, fluoropolymers, and vinyl. The Shore A scale is used for 'softer' rubbers while the Shore D scale is used for 'harder' ones. The shore A Hardness is the relative hardness of elastic materials such as rubber or soft plastics can be determined with an instrument called a Shore A durometer. If the indenter completely penetrates the sample, a reading of 0 is obtained, and if no penetration occurs, a reading of 100 results. The reading is dimensionless.

The Shore hardness is measured with an apparatus known as a Durometer and consequently is also known as 'Durometer hardness'. The hardness value is determined by the penetration of the Durometer indenter foot into the sample. Because of the resilience of rubbers and plastics, the hardness reading my change over time so the indentation time is sometimes reported along with the hardness number.

Table 1 Shore D Hardness of PTFE and its composites

Material	Hardness in ASTM-D
Virgin PTFE	60 shore D
25% Glass PTFE	70 Shore D

2.3 TRIBOLOGICAL TESTS

2.3.1 Specimen Details

The study was aimed at investigating the tribological behavior of Virgin PTFE, 25% glass filled PTFE of (30mmX10mm) discs against AISI 440C (7mmø) spherical pin. Set of reciprocating wear tests were performed using pin-on-disc tribometer. Briefly, Virgin PTFE, 25% glass filled PTFE of (30mmX10mm) samples were employed as discs and pin was made of AISI 440C (7mmø) was used.

2.3.2 Test Apparatus

Tribological testing uses tribometers or devices to measure wear and friction. Tribometer is an instrument for investigation of tribological properties. Tribometer is based on themovement of sliding between the surfaces and references (pin sliding on disc) and the testing is carried out under the controlled conditions of sliding, load, temperature, humidity and so as these factors strongly affect the tribological properties. The basic features of all the tribometers contain the equipment provides motion, imposing load and some kind of adapter which can detect and convert the physical values of testing into expected values.

Since our main concern was to study the un-lubricated friction and wear of the Virgin PTFE, 25% glass filled PTFE against AISI 440C spherical pin. Such test equipment like fretting test rig was sufficient to serve the purpose.

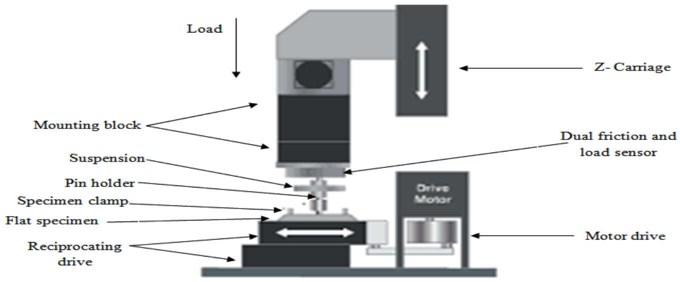

Figure 1. Schematic diagram of Tribometer

2.3.3 Experimental Procedure

Extensive studies on the Friction and wear tests were conducted under dry conditions (in order to eliminate the contribution of lubricant) on a computer controlled universal tribometer shown in figure 1,reciprocating test rig in pin-on-disk configurations under a reciprocating motion point contact wear mode. The pins stay over the discs with two degrees of freedom: a vertical one, which allows normal load application by direct contact with the surface of the disc, and a horizontal one, for friction measurement. The upper pin slides reciprocally with amplitude of 2.5mm on the stationary Virgin PTFE, 25% glass filled PTFE (30mmX10mm) discs. The friction coefficient curve was recorded automatically with a chart attached to the test rig. For comparative reasons, all the tests were performed with identical experimental parameters (frequency, load and sliding distance). The tests were performed at the following conditions:

a) Sliding distance tests – these tests were performed for a sliding distance of 2000 m in four steps, keeping the normal load, frequency and amplitude constant for each test. Friction coefficient and wear coefficient were measured after 500 m distance.

b) Load tests – these tests were performed at the normal load of 5 N, 10 N, 20 N and 30 N. The sliding distance, frequency, and amplitude were kept constant .Friction and wear coefficient were measured after each load test.

Before and after the test, the pins and discs were ultrasonically cleaned in acetone bath for 10 minutes (to remove the dust particle and contaminations present which affects tribological properties), dried in an oven at 50^{o}C for 10 minutes and weighted on an electronic balance 0.0001 g accuracy. After the tests, wear scar diameter of pin and the corresponding weight loss were recorded. These data were subsequently used in the calculation of wear rates presented in the results section of this thesis. For each experiment, the pin surface was used in the as-received condition and a new surface region was used for each test (except sliding distance tests) in order to ensure similar initial surface conditions.

2.4 ANALYSIS TECHNIQUE

2.4.1 Optical microscope

In the optical microscope, when light from the microscope lamp passes through the condenser and then through the specimen (assuming the specimen is a light absorbing specimen), some of the light passes both around and through the specimen undisturbed in its path. Such light is called direct light or undeviated light. The background light (often called the surround) passing around the specimen is also undeviated light.

Some of the light passing through the specimen is deviated when it encounters parts of the specimen. Such deviated light (as you will subsequently learn, called diffracted light) is rendered one-half wavelength or 180 degrees out of step (more commonly, out of phase) with the direct light that has passed through undeviated. The one-half wavelength out of phase, caused by the specimen itself, enables this light to cause destructive interference with the direct light when both arrive at the intermediate image plane located at the fixed diaphragm of the eyepiece. The eye lens of the eyepiece further magnifies this image which finally is projected onto the retina, the film plane of a camera, or the surface of a light-sensitive computer chip.

2.4.2 Scanning electron microscope

The SEM analyses were carried out on HITACHI S-3600N. The scanning electron microscope (SEM) is a microscope that uses electron rather than light to form an image. There are many advantages in using the SEM instead of a light microscope .The SEM has a large depth of field, which allows a larger amount of the sample to be in focus at the same time. Preparation of the sample is relatively easy since most SEMs only require the sample to be conductive. It is used gold to observe the morphology of combination of higher magnification , larger depth of focus ,greater resolution ,and ease of sample observation ,makes the SEM one of the most heavily used instrument used in the material science .The basic theory of the SEM functioning is explained. A beam of electron is generated in electron gun, located at the top of the column.

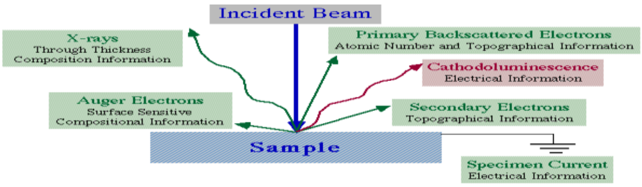

Figure 2. Schematic diagram of electron beam and specimen interaction in SEM

2.4.3 3D Profilometer

3-D Optical profilometry uses light instead of a physical probe. The key component to this technique is directing the light in a way that it can detect the surface in 3D. Examples include optical interference, using a co focal aperture, focus and phase detection, and projecting a pattern onto the optical image. In practice, an optical profiler scans the material vertically. As the material in the field of view passes through the focal plane, it creates interference. Optical profiling can be used to measure surface finish, roughness and shape on many surfaces, so long as enough light is reflected back into the objective from the surface.

Results and discussion

2.5.1 Tribological tests

Tribological behavior of Virgin PTFE, 25% glass filled PTFE was studied under dry unlubricated conditions using the pin-on-disc tribometer. Both the friction and wear of the materials were studied. The test conditions were varied to investigate the effect of sliding distance and load on tribological behavior. To allow comparisons, samples were tested under identical conditions**.**

2.5.1.1 Friction and wear behavior with sliding distance

In figure 3 and 4 graphs are plotted to compare the Coefficient of friction and wear loss with sliding distance of virgin PTFE and 25% glass filled PTFE at 500, 1000, 15000and 2000m.

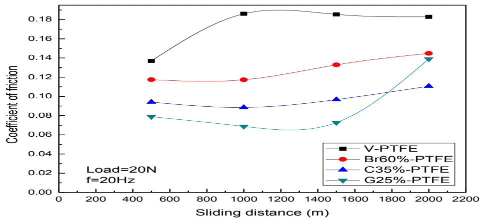

Figure 3. variation of coefficient of friction with sliding distance

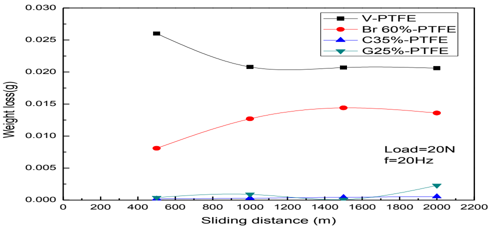

Figure 4. variation of weigh loss with sliding distance

In figure 3 and 4 graphs are plotted to compare the Coefficient of friction and wear loss with sliding distance of PTFE and its composite at 500, 1000, 15000and 2000m.

From figure 3 we can see that the coefficient of friction of virgin PTFE is highest among all other PTFE and the trend is also different with respect to the remaining grades of PTFE. In virgin PTFE the coefficient of friction keeps increasing till 1000m and then it seems to decrease till 1500m and remains linear or constant after 1500m and25% glass filled PTFE shows similar trend of coefficient of friction with increasing sliding distance.

From figure 4 we can see that the wear loss of virgin PTFE sample is highest among all other PTFE. Wear loss first decreased till 1000m and then about to remains constant after 1000m. 25% glass filled PTFE remains same with increasing sliding distance, which is negligible compared to virgin PTFE.

2.5.1.2 Friction and wear behavior with load

In figure 5 and 6 graphs are plotted to shows comparison in the variation of coefficient of friction and wear loss with respect to loads virgin PTFE and 25% glass filled PTFE. The load parameters are taken at 5, 10, 20 and 30 N.

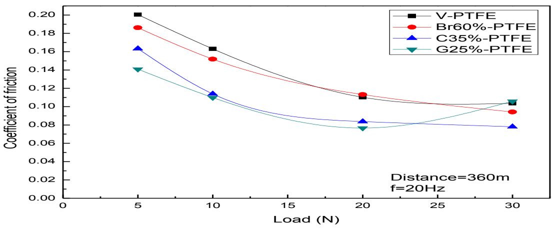

Figure 5. variation of coefficient of friction with sliding distance

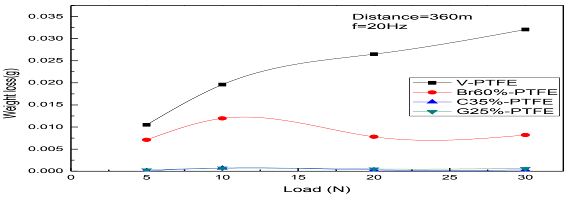

Figure 6. variation of coefficient of friction with sliding distance

Figure 5 shows the comparison in variation of coefficient of friction with load of Virgin PTFE and 25% glass filled PTFE. Loads are taken in the interval of 5, 10, 20 and 30N. From figure 4.5 we can observe that at low load the value of coefficient of friction is high. As soon as there is increase in load the value of coefficient of friction starts decreasing. For virgin PTFE the value of coefficient of friction lies between 0.2005 and 0.1037and for 25% glass filled the value of coefficient lies between 0.1409 and 0.1059. For load test sliding speed, distance, frequency are remains constant and the values are 0.2m/s, 360m, and 20 Hz respectively.

Figure 6 shows the comparison in variation of wear loss with load of Virgin PTFE and 25% glass filled PTFE and it is clear from figure that that the wear loss of virgin PTFE sample is highest among all other PTFE followed by 25% glass filled PTFE.

2.5.2 Optical microscope image

Figure 7. Optical microscope image after the sliding distance of 2000 m at 20 N load of (a) 25% glass filled and (b) virgin PTFE.

From the above figure of optical microscope we can easily explain the trend of the graph of coefficient of friction and wear loss on the basis of sliding distance. In static sliding distance test there is transfer of material from polymer to metal surface initiates because of adhesion between the two materials which during sliding contributes to shear in the subsurface region of the contact. Initially in the starting of sliding distance test there is a thin film of material transfer from polymer disc to the pin. As soon as there is increase of sliding distance the whole counterpart surface is covered with thick film of polymer. So in the case of virgin PTFE the coefficient of friction graph first increased up to 1000m and then its starts decreasing after it and remains approximately constant. But in case of filler materials such as 25% glass filled PTFE, trend of graph is different. As soon as we increase the percentage of filler material gets fragile in nature. In case of all the filler material coefficient of friction first decreased up to1000m and after that it starts increasing, the reason behind this is that at starting there is a transfer of thin film between tribopair which cause in reduction of coefficient of friction. But at higher sliding distance there is transfer of material from pin which is clearly shown in figure 7. So at the higher sliding distance there is increase in coefficient of friction due to abrasion of the material which can be easily seen in the optical microscope image in figure 7.

Figure 8. Optical microscope image after load test load of (a) 25% glass filled at 30N and (b) virgin PTFE at 30N**.**

Microscopic image shown in figure 8 are carried out for 30N load of (a) 25% glass filled at 30N (b) virgin PTFE. Images shows that at higher load there is more abrasion on virgin PTFE compared to 25% glass filled PTFE.

By observing graph in figure 6 and 7 we can say that all polymer composites follows same trend of graph. With increasing load there is a decrease in coefficient of friction, It is known that polymers are a visco-elastic materials their deformation under load is visco-elastic. Therefore, the variation of friction coefficient with load follows the equation μ where μ is the coefficient of friction, N is the load, k constant and n is also a constant, its value $2/3 < n < 1$. According to this equation, the coefficient of friction decreases with the load increase. But when the load increase to the limit load values of the polymer, the friction and wear will increase due to the critical surface energy of the polymer.

From figure 6 we can see that apart from pure ptfe the specific wear rate for PTFE composites decreases with the increase in load value. the order for wear rate of ptfe is given as: virgin PTFE>25% glass filled. in the case of pure PTFE and PTFE + 25% glass fiber, it is seen that thePTFE with no filler and with glass fiber reinforcement form a good thin and uniform transfer film.

III. Conclusions

In this study, reciprocating wear tests were conducted to investigate the friction and wear characteristics of virgin PTFE and 25% glass filled PTFE. The material used as the counter part is AISI 440c. As a result of the test programme, the following conclusions were made.

1. Wear studies against AISI 440C stainless steel pin counter face under various loads and sliding distance (sliding speeds), materials used in this study were ranked as follows for their wear performance. PTFE+ 25% Glass >Virgin PTFE. PTFE + 25% Glass exhibited best wear performance.
2. The friction coefficient of pure PTFE and its composites decreases when applied load increases.
3. Pure PTFE is characterized by high wear because of its small mechanical properties. Therefore, the reinforcement PTFE with glass fibers improves the load carrying capability that lowers the wear rate of the PTFE.

For the specific range of load and speed explored in this study, the load has stronger affect on the wear behavior of PTFE and its composites than the sliding velocity.

References

[1]. N.K. Myshkin, M.I. Petrokovets, A.V. Kovalev. “Tribology of polymers: Adhesion, friction, wear, and mass-transfer”, Tribology International 38 (2005) 910–921.
[2]. Jaydeep Khedkar , Ioan Negulescu , Efstathios I. Meletis. “Sliding wear behavior of PTFE composites”, Wear 252 (2002) 361–369.
[3]. H. Unal a, U. Sen a, A. Mimaroglu b. “An approach to friction and wear properties of polytetrafluoroethylene composite”, Materials and Design 27 (2006) 694–699.
[4]. S. W. Zhang. “State-of-the-art of polymer tribology”, PII: S0301–679X(98)00007–3.
[5]. Gao Jintang. “Tribochemical effects in formation of polymer transfer film”, Wear 245 (2000) 100–106.

[6]. V.N. Aderikha a, A.P.Krasnov , V.A.Shapovalov , A.S.Golub. "Peculiarities oftribological behavior of low-filled composites based on polytetrafluoroethylene (PTFE) and molybdenumdisulfide Wear320(2014)135–142.

[7]. Shangguan Qian-qian a, Cheng Xian-hua. "On the friction and wear behavior of PTFE composite filled with rare earths treated carbon fibers under oil-lubricated condition", Wear 260 (2006) 1243–1247.

[8]. Bao Dandan ,Ch eng Xianhua . "Evaluation of Tribological Performance of PTFE Composite Filled with Rare Earths Treated Carbon Fibers under Water-Lubricated Condition", JOURNAL OF RARE EARTHS 24 (2006) 564 – 568.

[9]. S. Bahadur, V K Polineni. "Tribological studies of glass febric-reinforced poltamide composites filled with CuO and PTFE". Wear 200(1996) 95-104.

[10]. HitonobuKoike, KatsuyukiKida , KoshiroMizobe , XiaochenShi , ShunsukeOyama , YujiKashima. "Wear of hybrid radial bearings (PEEK ring-PTFE retainer and alumina balls) under dry rolling contact", Tribology International 90(2015)77–83.

[11]. MarcelloConte n, BihotzPinedo,AmayaIgartua. "Role of crystallinity on wear behavior of PTFE composites", Wear307(2013)81–86.

[12]. M. Conte , A.Igartua. "Study of PTFE composites tribological behavior", Wear 296 (2012) 568–574.

[13]. J.R. Vail, B.A. Krick, K.R. Marchman,W. Gregory Sawyer. "Polytetrafluoroethylene (PTFE) fiber reinforced polyetheretherketone (PEEK) composites", Wear 270 (2011) 737–741.

[14]. Luigi Mazza , AndreaTrivella , RobertoGrassi , GiulioMalucelli, "A comparison of the relative friction and wear responses of PTFE and a PTFE-based composite when tested using three different types of sliding wear machines", Tribology International 90(2015)15–21.

[15]. Z. Rymuza, "Tribology of Polymers", archives of civil and mechanical engineering Vol. VII 2007 No. 4.