Investigation of the effect of micro-fillers on Viscoelastic and Erosion wear Characteristics of PTFE composites

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Abstract

Polytetrafluoroethylene (PTFE) is one type of the most prominent semi-crystalline engineering thermo-plastics. The functional properties of PTFE are enhanced with the addition of micro-fillers in order to increase the utility of the composites. In the current work, three types of industrial Teflon composites with micro-fillers viz. 25% by weight of glass fibers, 25% by weight of carbon fibers, and 25% by weight of graphite along with neat PTFE were used to investigate the viscoelastic and erosion wear characteristics. From the Dynamic Mechanical Analysis (DMA) graphs, it was observed that PTFE with 25% by weight of GF has shown peak viscoelastic characteristics in three-point bending mode. The viscoelastic properties such as storage modulus of 1 GPa, loss modulus of 84 MPa and a tanδ of 0.137 respectively at 140°C were observed from the DMA plots for the sample (PTFE+25%GF). Also, the erosion wear behavior of the same sample has shown good resistance at 1.5 bar and 90° impingement angle respectively due to the addition of glass fiber micro-filler.

Keywords: PTFE composites, glass fibers, carbon fibers, graphite, viscoelastic properties, erosion wear

I. Introduction

For more than sixty years, our world and the nature of its occupant's lives have been improved by a resin known as polytetrafluoroethylene or PTFE. It is found in 1938 by a DuPont scientific expert, Mr. Roy J. Plunkett. Upon assessment, DuPont discovered that PTFE gave a mix of grating, temperature, substance, mechanical and electrical opposing properties. PTFE, is recorded in “The Guinness Book of World
Records” for the most minimal coefficient of static and dynamic grating as 0.02 - proportionate to wet ice on wet ice [VI]. Nowadays Polymer composites are being prominently used in many products such as automobile components, textile machinery parts and many other products. Among polymers engineering plastics such as PTFE, nylon and PPS are commonly used in many friction and wear applications. Out of the above three PTFE is one important and commonly used polymer for bearing and wear resistant applications. Hence the present study is focused on PTFE based composites.

PTFE composites diminished grating and wear when used as dry oils in aviation bearing applications [XI]. NASA encouraged tests on journal bearings with PTFE greasing up liners demonstrated grinding and wear qualities good with airframe bearing prerequisites [VI]. Most orientation related with flight-control applications in fixed wing airplane and helicopters utilize slight layers of PTFE based composites clung to metal substrate [XII]. PTFE is a sort of self-greasing up material having excessively low coefficient of erosion, exceptional corrosion obstruction, concoction dormancy and wide assistance temperature run [X]. Polymer composites are as a rule more and more utilized as basic segments that are all the time exposed to vibrations, grating and wear loadings under various temperatures. In specific circumstances, the coefficient of grinding is of the most elevated importance, however generally it is the mechanical burden conveying limit and the wear life of segments that decide their agreeableness in modern applications under various working conditions. In such utilizations of composite materials, disintegration, expulsion of material because of impingement of strong particles, is one of the most important crash modes.

At the point, when a target surface was hit by the quickened sand and liquid at various edges cause loss of material by the process of erosion [VII]. The notable phenomenon is when the parts work in dusty situations in different mechanical applications. The adjustment in surface properties because of consistent effect of the entrained particles can decrease at last the working existence of the parts. The applications, for example, pipelines secured with PTFE lining conveying synthetic compounds, slurry, the impeller blades of positive displacement pump are to set not many instances of the circumstance. Therefore, to diminish the regular substitution of these parts the surface coating material ought to have low disintegration wear characteristic. As the rate of wear of erosion is a dynamic in nature and affected by boundaries, for example, striking speed of the hard particles, point of impingement, shape and size of sand particles, hard erodent properties, and targeted surface material properties [X], [XI]. These parameters are described in a fish bone diagram as shown in Fig. 1. Hence, in the current paper the work is focused on dynamic mechanical
properties of the PTFE composite samples and erosion wear influencing parameters as well.

![Fishbone diagram](image)

Fig. 1 The erosion wear rate of wear affected parameters: Fishbone diagram

II. Materials and Techniques

Commercial grade PTFE based composite samples were delivered by Hindustan Polymers, Sangli, India. The short glass fiber (GF) content is 25% by weight, the short carbon fiber (CF) content is 25% by weight, and particulate graphite content is 25% by weight are added in neat Teflon and are fabricated by compression molding followed by sintering using variable heating and cooling cycle.

III. Dynamic Mechanical Analysis

Numerous materials, including polymers, carry on both like a an elastic solid and a viscous fluid, accordingly the term viscoelastic. DMA works predominantly in the straight viscoelastic range and is in this manner progressively delicate to the structure. DMA measures the viscoelastic properties utilizing either transient or dynamic oscillatory test. The most well-known test is the dynamic oscillatory test, where a sinusoidal pressure is applied to the material and a sinusoidal strain is estimated. Hence, by using DMA, properties such as, the storage modulus and loss modulus of polymers/composites can be investigated under the action of dynamic oscillatory (sinusoidal type) loads. DMA tests are performed in the constraints of temperature from room temperature to 150°C range in three-point bending configuration. Amplitude of 1µm with a frequency of 1 HZ. The samples with 60 mm length, 10 mm width and 3 mm are used for the DMA test. The DMA tests were conducted as per ASTM D4065 standard on all PTFE composite samples. The specimen test set up in three point bending mode is shown in Fig. 2.
IV. Erosion Wear Test of PTFE composite samples:

Erosive wear tests were performed according to ASTM G76 to evaluate the performance of PTFE filled composites exposed to erosive environment at room temperature. An air jet erosion test rig is designed and manufactured by MAGNUM, Bangalore (India), as per ASTM standards was used for evaluation. The tests were performed on a standard test rig of air impingement erosion as shown in Fig. The erodent particles chose as silica sand (40-100 microns size) and were quickened by packed air, leaving from a tungsten carbide nozzle (length 63 mm, measurement 1.5 mm). The quickened particles at long last hit the objective surface which was from nozzle focus by 10 mm. The estimations were finished by methodology portrayed by Smith et al.. The speed of the particles was resolved as 86 m/s, 101 m/s, and 119 m/s at 0.5 bar, 1bar, and 1.5 bar individually, by utilizing the twofold circle technique. All the examples were tried in the chamber at room temperature.

Fig. 2 Schematic of DMA three-point bending mode

![Schematic of DMA three-point bending mode](image)

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![Specimen holder orientations](image)

Fig. 3 Specimen holder orientations: (a) $\theta = 90^\circ$ (b) $\theta = 60^\circ$ (c) $\theta = 30^\circ$
V. Results and Discussion

Dynamic Mechanical Analysis

Because of the use of sinusoidal loads, the elastic modulus showed by the material declines over some undefined time frame as a result of the atomic reworking trying to limit confined localized stresses. The parameters, $E'$, the storage modulus is the elastic part and identified with the examples stiffness. $E''$, the misfortune modulus, is the viscous part and is identified with the examples storage to disseminate mechanical energy through atomic movement. $\tan \delta$, is another basic boundary that gives data on the connection between the elastic and inelastic segment.

Storage modulus is the energy put away elastically during deformation [VI]

$$E' = E^* \times \cos \delta$$

(1)

Loss modulus is the energy loss during deformation [VI]

$$E'' = E^* \times \sin \delta$$

(2)

where, $E^* = \text{Complex dynamic modulus} = E' + i E''$

Loss tangent or loss factor is an estimation of the material damping and it shows the ability of material to dissipate the energy

$$\tan \delta = \frac{E''}{E'}$$

(3)

Values of the storage modulus, loss modulus and tan delta are measured by equations (i) - (iii). The storage modulus is therefore the function of the output or responding
frequency, and the decrease in bending amplitudes was noticed as a function of time and were taken for damping calculation of PTFE composites. The viscoelastic properties such as storage modulus, loss modulus, and Tan δ were depicted as shown in Fig. 5 for the selected PTFE composites. From these plots it was observed that PTFE with 25% Graphite shown less stiffness and more fluid characteristic whereas PTFE with 25% glass fibers shown more stiffness and less fluid characteristic.

![Fig. 5 viscoelastic properties of the selected PTFE samples: a) Storage modulus vs. Temperature; b) Loss modulus vs. Temperature; c) Tan δ vs. Temperature](image)

**Erosion Wear Test of the samples:**

The mass lost by the samples after erosion test (Δm) was estimated through a precision balance with 0.0001 g accuracy. Finally, the erosion rate of wear was estimated by using the equation (iii) [VI]

\[
Erosion\ wear\ rate, E_{wr} = \frac{\Delta m}{M}
\]

(4)

The plots of erosion wear rate by keeping pressure as constant for increasing the impingement of air nozzle angle and the erosion rate of wear by keeping angle as constant for varying pressure were shown in Fig. 6.
Fig. 6 (a) – (c) plots of erosion wear rate vs. impingement angle; (d) – (f) plots of erosion wear rate vs. pressure

The erosion wear rate of neat PTFE is found to be more when compared to PTFE composites loaded with 25% by weight micro-fillers. As, in case of neat PTFE the PTFE chain is exposed directly to the entrained particles. It is also found that at low impingement angles ~30° the wear rate is more relative to other impingement angles and the same is reduced at high impingement angles [VII]. PTFE with 25% by weight graphite has shown more wear rate relative to neat PTFE at 60° impingement angle, due to the fact that addition of soft filler further increased the ductility of neat PTFE and micro-cutting with the repeated hitting of the entrained particles and reached maximum wear rate at pressure 1.5 bar. A similar kind of phenomenon was also observed from the work of Satapahy et al. [XI]. Out of the four composites examined, PTFE with 25% by weight glass fibers has shown good erosion wear resistance due to better bonding of glass fibers particles with fluorine, being fluorine atoms soft and depletes fast. These fluorine atoms may be well protected with the glass fiber particles. Also, from DMA tests PTFE with 25% by weight glass fiber loading has shown better viscoelastic properties. It is concluded that, the PTFE composite loaded with 25% by weight glass fiber can be recommended for several erosion wear applications.

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VI. Conclusions
The following conclusions were made from the study of erosion wear of PTFE composites:

- DMA plots show better viscoelastic properties for PTFE with 25% by weight glass fiber micro-filler loading, i.e., the storage modulus, loss modulus, and damping properties were superior to other PTFE composites.
- PTFE with 25% by weight glass fiber loading showed very good erosion wear resistance for higher impingement angles (60°–90°) of entrained particles. As the new layer of glass fibers reinforcement surface was exposed to the accelerated erodent particles.

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