TRIBOLOGICAL BEHAVIOR OF PTFE COMPOSITES – A REVIEW

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ABSTRACT *The tribological behavior of various reinforcement materials filled Polytetrafluoroethylene (PTFE) composites were studied and compared. A comparative study of different PTFE composites is showing how properties of PTFE can be improved in tribological aspects. It was observed that wear rate of PTFE composites decreased when concentration of filler materials increased to certain limits; however, it leads to softness of the PTFE composites. It was also observed that decrease in wear rate is due to the presence of transfer film at rubbing surfaces. The aim of the present paper is to focus on the work done in the area of PTFE composites and also the impact analysis of filler materials on tribological performance of PTFE composites.*

Keywords: *Friction and wear, PTFE composites, Tribological behaviour*

I. Introduction

1.1 Tribology

Tribology is the science of interacting surfaces in relative motion. It includes the study of friction, wear, lubrication, and the design of bearings [1]. The word "Tribology" has been used for: Basic mechanisms governing interfacial behavior, Basic theories quantifying interfacial mechanisms, Solutions to friction and wear problems. This field is extended to various areas such as, chemistry, materials science, physics and engineering. The tribology became widely used in 'The Jost Report', published in 1966 [2]. The report shows the importance of cost of friction, wear and corrosion to the UK economy. Implementation of tribological knowledge provides economic benefits by reducing energy loss due to friction, loss due to breakdowns, reducing depreciation of machinery.

1.2 Polytetrafluoroethylene (PTFE)

A solid lubricant called Polytetrafluoroethylene (PTFE) polymer is a widely used in various industry due to its lower dry sliding friction coefficient $\mu < 0.2$. It has an excellent material property which includes: a low coefficient of friction, chemical inertness and thermal stability to a relatively high melt temperature, resistance to chemical attack in a wide variety of solvents and solutions, high melting point. These properties make PTFE a popular material and it is commonly used in bearing and seals applications. However, PTFE suffers from poor wear resistance, poor mechanical strength and excessive viscoelastic deformation which hamper its use as lubricant component of composite tribo-materials [3]. By addition of suitable filler material, the wear resistance of PTFE can be significantly improved. The solid lubricants such as, graphite and Molybdenum disulfide and most commonly used filler materials for tribological applications are carbon, bronze, glass fibers in different percentage for improving wear resistance and friction coefficient. The addition of filler materials also affects the thermal conductivity, chemical inertness, electrical conductivity, abrasiveness. Generally the wear resistance improves from 10 to 500 times and increases the thermal conductivity from 2 to 3 times with the addition of fillers [4]. The wear resistance and dry sliding friction coefficient of PTFE matrix can also be improved by addition of hard particulate fillers made of metal particles, and fiber fillers made of glass. Aim of this work is to evaluate the effect of different filler materials on the tribological performance of PTFE composites.

II. Literature review

In the past, considerable research work has been done on the improving tribological behavior PTFE composites, while most of them focus on nano - particle reinforcements. Other research on the tribological performance of micro-size reinforcements covers the loading range between 0 and 25 wt% [5]. Sawyer et al. [6] found that polymer composites filled with higher concentrations of hard reinforcements could yield low wear rates, because wear resistance is related to the hardness of the materials up to certain extent. Investigation on effect of filler crystal structures was presented by shi et al. [7] finding that the friction coefficient of various PTFE composites are strongly dependent on filler crystal structure but the improvement of anti-wear properties is more dependent on filler shape. Wang et al. [8] investigated the effect of addition of polyetheretherketone (PEEK) with various weight fractions of silicon carbide (SiC), Silicon nitride (Si3N4), silicon dioxide (SiO2), and Zirconium dioxide (ZrO2). The improved wear resistance and reduced the friction coefficient was found with the addition of the filler infractions less than 10 wt. %. This is due to two factors: the smoothing of the steel counter face, and the development of a transfer film.

Li et al. [9] studied nanoparticles of Zink oxide (ZnO) filled PTFE composites and found that wear resistance was improved by nearly two orders of magnitude with a maximum wear resistance at ZnO concentrations of roughly 15% by volume. In that study, the friction coefficient of the nanocomposite was higher than the unfilled PTFE. There have also been some reports on the use of particulate filler materials like Molybdenum disulfide (MoS2) and graphite to modify the tribological properties of PTFE [10]. Tanaka et al. [11] have studied the effect of addition of glass fibers and MoS2 fillers on the friction and wear properties of PTFE. It was also observed that the addition of MoS2 alone does not impart a good wear resistance to PTFE, during sliding.

Zang et al.[12] studied the friction and wear properties of metal powder filled PTFE composite under oil lubrication and reported that copper (Cu), lead (Pb) and nickel (Ni) increased the load bearing capacity and reduced the wear of PTFE composite. A traditional way to improve the properties of polymers is to addition of fibers (glass or carbon) or filler material (organic, inorganic and metallic particulates). The addition of filler materials to polymers can enhance the mechanical, thermal, impact, electrical and tribological properties [13]. However, graphite which has high thermal conductivity and low cost can be used with polymer for bearing to increase conductivity and to reduce lubrication. Even though some filler materials are added to the polymers, their effects on tribological properties are not clearly known.

HuLin Li et al. [14] studied the Tribological behavior of hybrid PTFE / Kevlar fabric composites with nano - Si3N4 and submicron size Tungsten disulfide (WS2) fillers. The composite specimens were prepared with nano- Si3N4 and sub micron size WS2 as fillers. The scanning electron microscopy (SEM) was used to analyze the morphologies of the worn surface, transfer film and debris. The results indicate that single nano-Si3N4 fillers can effectively reduce the wear rate of composites, but they donot reduce the friction coefficient. Hybrid Si3N4 and WS2 fillers can significantly reduce the wear rate and friction coefficient of composites.

V.N. Aderikha et al. [15] investigated the Mechanical and tribological behavior of PTFE–polyoxadiazole fiber composites. It is found that fiber treatment raises the composite density, heat resistance, mechanical strength and improves its tribological behavior. The tensile strength of the 10%-filled composite increases by more than 20% and elongation at break by 50% compared to the composite filled with the original fibers. Based on the results of IR-spectroscopy and SEM it is concluded that filler treatment produces a fluoro organic coating with good wet ability by the matrix polymer which reduces the void content and raises adhesion between the matrix and the fibers. It is also concluded that, some improvement in the wear rate is observed at high specific loads.

W. Gregory Sawyer et al. [16] studied the friction and wear behavior of PTFE filled with alumina nanoparticles. A compression molding was used to prepare solid lubricant composite material of PTFE and 40 nm alumina particles. The constituent powders were blended using a jet milling apparatus. Composites from 0 to 20 wt.% were prepared. These composites were tested against a polished stainless steel counterface on a reciprocating tribometer. The experimental conditions were a contact pressure of 6.4MPa, a stroke length of 50 mm, and a sliding speed of 50 mm/s. The friction coefficient of the composite increased over unfilled samples from roughly $\mu = 0.15$ to $\mu = 0.2$. At filler concentrations of 20 wt.%, the wear resistance improved 600×. The wear resistance of this composite increased monotonically with increasing filler concentration and no optimum filler fraction was found.

Recent investigations on Wear and friction performance of PTFE filled epoxy composites with a high concentration of SiO2 particles by J.T. Shen et al. [17] shows an ultra low coefficient of friction (CoF) under a load of 60N with optimum content of PTFE lies between 10 and 15wt%. It also shows that low wear rate of the composite when dry sliding against bearing steel balls within 1000m. The tribo-results show that within 1000m sliding distance the Epomet – PTFE composites with optimum con- tents of PTFE exhibit a good tribological performance under 60N load. In the steady-state of sliding, smearing of the PTFE particles along the worn surface was observed together with fracturing of the SiO2 particles and cracking of the epoxy matrix. The thickness of the tribo layer was measured about 20–30 nm on the surface of SiO2 particles after sliding for more than700m.

G.Y. Xie et al. [19] focused on the tribological behavior of polyetheretherketone (PEEK) / polytetrafluoroethylene (PTFE) composites reinforced with potassium titanate whiskers (PTW) using the pin-on-disk configuration under dry sliding conditions at different applied loads. It was found that the PTW reinforced PEEK/PTFE composites exhibited much better tribological properties than those without PTW.

Both the friction coefficient and the wear rate decreased with the increase of the PTW content. Moreover, the friction coefficient and the wear rate of the composites showed a decreasing tendency with the applied loads increasing from 1.0MPa to 2.0 MPa.

Zhen Zuo et al. [20] have filled Polyethersulfone (PES) into polytetrafluoroethylene(PTFE) to improve the tribological property of this type of polymer. The addition of PES improved the anti-friction and wear resistance of the PES/PTFE composites better than that of the virgin PTFE. The interaction between the PTFE transfer film and the PES layer was found at the friction interface. The composite with the PES addition of 40wt% exhibits the best tribological property of all the PES/PTFE composites, attributing to the coexistences of the uniform PTFE transfer film and the continuous PES layer.

Investigations on the tribological behavior of the hybrid PTFE/cotton fabric composites filled with microsize Antimony Oxide Powder (Sb2O3) and melamine cyanurate (MCA) by Hui-juan Zhang et al.[21] shows that the wear rate of the hybrid PTFE/cotton fabric composites decreased when Sb2O3 was used as the filler but increased with MCA filler. It was also shows that hybrid fillers had a wear reduction effect on the hybrid PTFE/cotton fabric composites at lower loads but increased the wear rate at higher loads. The wear behavior of the composites was explained in terms of the topography of worn surfaces and transfer film formed on the counter part pin.

Fei Li et al. [22] focused on tribological behaviors of copper-coated graphite filled PTFE composites. The compression molding was used to prepare Polytetrafluoroethylene (PTFE) composites filled with different fillers and various filler proportions. The selected fillers were powders of graphite, copper, copper-coated graphite (CCG), and copper-mixed graphite (CMG). The tribological behaviors of composites were evaluated on an MM-200 friction and wear tester. The scanning electron microscopy (SEM) and X-ray photo electron spectroscopy (XPS) were used to examine the morphologies and element chemical states of the worn composite surfaces respectively. It was found that Graphite–PTFE composite in sliding against the stainless steel presented the lowest friction coefficient, but higher wear rate compared with CMG–PTFE and CCG– PTFE. The wear mechanism of graphite–PTFE and CCG– PTFE composites was mainly due to the adhesion wear, while CMG–PTFE to both the abrasion wear and the adhesion wear.

III. DISCUSSION

Table 3.1: A comparison of the lowest reported wear-rates for various PTFE composites

Reference	Matrix / filler	Lowest wear rate ($\times 10^{-6}$ mm^3 / Nm)
22	Unfilled PTFE	730
9	PTFE / ZnO	13
14	PTFE / Kevlar - 7.5wt% WS_2 + 12.5wt% Si_3N_4	4.1
18	PTFE / 15 vol.% Bronze	67.19
19	PEEK / PTFE - 15wt% potassium titanate whiskers	3.5
20	PTFE / 40% PolyEtherSulphone	0.55
21	PTFE / cotton fabric + 10 wt% Sb_2O_3	6.02
22	PTFE / copper-coated graphite	1.9
23	PTFE / Graphite 4% + nano - Titanium dioxide (TiO2)	16.6

In Table 3.1 the lowest reported wear-rates for various fillers mixed PTFE composites are given. In some studies discussed above not enough information was available to place the data on either such a plot or such a table. It is clear that, the use of the fillers remarkably reduced the wear rate of the PTFE composites.

It should be note that the unfilled PTFE matrix material shows a wear rate of about 730×10^{-6} mm^3 / Nm, which is higher than that of composites. This indicates that fillers are beneficial to increasing the wear and friction-reducing ability of PTFE. However, it should be noted that while sliding against a stainless steel ring, the unfilled PTFE and PTFE composites shows marginal differences in the friction-reducing ability. It is also interesting to note that PES filled PTFE composites exhibit lowest wear rates among all the other PTFE composites. The copper coated graphite PTFE composites also exhibit better wear performance compared to other composites. Moreover, the improvement in tribological performance of the PTFE composites due to development of transfer film between the rubbing surfaces. It was observed that the developed transfer film protects the rubbing surfaces and has lubricant behavior in case of graphite, molybdenum disulphide filled PTFE composites. This process leads to much lower friction temperature, which leads to reduction in material loss due to wear.

IV. CONCLUSIONS

The effects of filler materials on the tribological behavior of PTFE composites have been studied. This review work shows that importance of reinforcements in improving coefficient of friction wear resistance of PTFE composites. The following conclusions can be drawn:

1. The tribological property of PTFE is improved effectively by the blending of PES. PES/PTFE composites will be more suitable for the applications in high load-low velocity systems rather than low load-high velocity systems.
2. Copper coated Graphite–PTFE composite in sliding against the stainless steel presented the lowest friction coefficient and improved wear resistance.
3. potassium titanate whiskers (PTW) filled PEEK/PTFE composites could greatly improve the wear resistance and reduce the friction coefficient. The friction coefficients and wear rates of the composites decreased with the increasing of the PTW content at different applied loads. Especially, when the PTW content was beyond 5 wt%, the enhancement in wear resistance was more effective.

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