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The tribological behaviour of glass filled polytetrafluoroethylene

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Abstract

Polymers and polymer composites are steadily gaining ground over metals in the field of engineering applications in tribology. Laboratory wear tests were carried out under ambient temperatures with no lubricant as well as in distilled water at an average sliding velocity of 0.2 m/s and contact pressures of 2.6–6.4 MPa. Three forms of glass viz. glass fibres, glass beads and glass flakes, each with a content of 25% weight were used in this study. Both hollow and solid glass beads were used. The sliding wear of the different glass filled PTFE composites was dependent on their ability to form transfer films on the counterface. The glass bead filled PTFE showed comparatively thicker films and higher wear rates than other forms of glass filled grades. The glass fibres and solid glass beads showed the lowest wear whilst hollow beads showed the highest under both low and high pressures due to crumbling and crushing of the beads during the sliding process. The glass flake filled PTFE showed relatively high but stable wear results up to 4.5 MPa above which the wear rate increased dramatically. A marginal increase in wear was achieved by using high aspect ratio glass fibres to the PTFE matrix. No correlation between the size of glass reinforcement and wear rate was established. The addition of a lamellar solid lubricant to the glass fibres reduced both the wear and friction of PTFE. The study of the transfer film growth by means of an optical microscope revealed that it was due to the mechanical interlocking of the polymer fragments into the metal asperity valleys. The compositional changes in the transfer film were studied by XPS which, among other things, showed presence of metal fluoride on the metal counterface.

Keywords: PTFE; Transfer films; Wear; Sintering

1. Introduction

Polymeric materials find increasing use in a wide number of applications where their resistance to wear is critical. Their applications range from bearings for machinery parts and biomedical joint replacements to their use as glazing materials where can damage result in the loss of optical properties [1]. Polytetrafluoroethylene (PTFE) is widely used as a bearing material due to its unique properties such excellent chemical resistance, low coefficient of friction and high-temperature stability [2,3]. In spite of the low coefficient of friction exhibited by PTFE when slid or rubbed against metal counterfaces, its poor wear resistance often impedes its utilisation in tribological systems. The wear rate of unfilled PTFE is often quoted to be about 10^{-3} mm^3 N^{-1} m^{-1} [4–6]. This wear rate is higher than that exhibited by the other self-lubricating polymer bearing thermoplastics such as polyamide (nylon) and polyethylene.

Much research has been done over the years on the friction and wear mechanisms of polymers and their composites in an effort to optimise material selection in mechanical engineering design and to develop new types of self-lubricating materials. Special attention has been paid to the relation between polymer structure and measured friction, and wear properties as well as the role of polymer transfer films formed on the counterface. The low coefficient of friction exhibited by PTFE when slid against metal counterfaces is often attributed to its smooth molecular profile with the larger fluorine atoms completely shielding the carbon backbone. Thus, the ability of PTFE extended chain linear molecules, –$(CF_2–CF_2)_n$–, to form low shear strength films on the mating counterface during the sliding process accounts for the exceptionally low coefficient of friction [4,7]. The high wear rates exhibited by PTFE is often attributed to its unique molecular structure [7,8]. Transmission electron microscopic results indicate

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that PTFE has a 'banded' structure with crystalline slices about 200 Å thick separated by thin amorphous regions [7]. The wear debris formed by PTFE upon rubbing against hard counterfaces occurs in the form of fibres and film that are thought to originate from slip within the amorphous regions. The connection between crystalline slices results in the formation of a fibre while the laterally connected fibres form a film [6]. The wear rate of PTFE can be significantly improved, by up to three orders of magnitude, by the incorporation of organic and inorganic fillers or combinations thereof [3,4,9–12]. However, the mechanism by which fillers improve the wear resistance of PTFE remains unclear [3]. Commonly used fillers for PTFE bearings include glass, bronze, carbon and Kevlar [2]. The type, shape, hardness, alignment, concentration and size of filler affect the tribological properties of polymer bearings [7]. The selection of a suitable filler is often a compromise between the properties required and the friction and wear of the polymer. Glass is often used as a filler of choice for PTFE, especially under harsh environmental conditions, with the level of glass often between 15 and 25% by volume [13].

Lancaster [14] showed that the addition of high aspect ratio filler materials such as carbon fibres and glass fibres to the PTFE matrix improves its wear resistance by preferentially supporting the load. Briscoe and Brainard [15] further showed that composites containing glass beads modify the counterface by severe abrasion whereas composites containing fillers of low abrasiveness are much more sensitive to counterface roughness. The addition of lamellar fillers such molybdenum disulphide (MoS_2) and graphite to PTFE improves the coefficient of friction as a result of their low shear strength. The effect on wear of incorporating MoS_2 to PTFE is complex though improved wear performance is reported when incorporated with other fillers [6]. The ability of fillers to reduce wear of PTFE is often linked to their ability to form an adherent and coherent transfer film on the counterface by mechanical interlocking of composite fragments into the asperity valleys of the mating surface. Chemical bond formation, which enhances the adherence of the transfer film, is reported to occur at the polymer/metal interface by various researchers [16–18]. The purpose of the present study is to elucidate the friction and wear of glass filled PTFE under dry and lubricated sliding wear conditions and to investigate tribo-chemical effects in polymer/stainless steel wear couples.

2. Experimental

2.1. Test materials

Different forms of glass, viz. glass beads, glass fibres and glass flakes, were used as fillers for PTFE with each composite having a filler content of 25 wt%. All these grades were compression moulded and free sintered to billets. The physical and mechanical properties of the different PTFE composites are shown in Table 1. The polymer wear samples used in the investigation were cut from the billets and machined to rectangular pins with the dimensions $10\times10\times24$ mm in length. A 45° chamfer was cut along the leading and trailing edges of the wear pin surface giving an initial cross-sectional area of about 90 mm^2. The stainless steel counterfaces were machined from grade AISI 431 with a hardness of about 460 HV30. The initial surface roughness of the counterface was kept constant at 0.2 μm R_a by surface grinding. A Taylor Hobson surface profilometer was used to measure the centre-line average (R_a) roughness of the counterface in a direction perpendicular to the grinding direction. The materials used in this investigation were supplied by Chemplast Marc Etter (Pty) Ltd.

Table 1
The physical and mechanical properties of PTFE composites

Material designation	Filler			Hardness, shore D
	Form of glass in PTFE	Size	wt%	
GFPTFE	Glass fibre	0.2–1 mm	25	62
SL/GFPTFE	Glass fibre+solid lubricant	0.8–2 mm	25+2	64
HGBPTFE	Hollow glass bead	2–35 μm	25	61
SGBPTFE	Solid glass bead	2–35 μm	25	62
GFLPTFE	Glass flake	1–8 μm	25	68

2.2. Test apparatus

The friction and wear tests were carried out on a reciprocating sliding wear rig which consists of a wear pin sliding perpendicular to the grinding marks on a flat counterface shown schematically in Fig. 1. This is a standard wear rig used for friction and wear and is fully described elsewhere [19,20]. Each test was performed on a new wear track covering a totalling sliding distance of 5 km. The linear reciprocating sliding wear rig reproduces the reciprocating motion typical of many real-world mechanisms, thus, the apparatus is frequently used to test wear performances of materials. The velocity for the reciprocating sliding wear rig is sinusoidal with an average velocity of

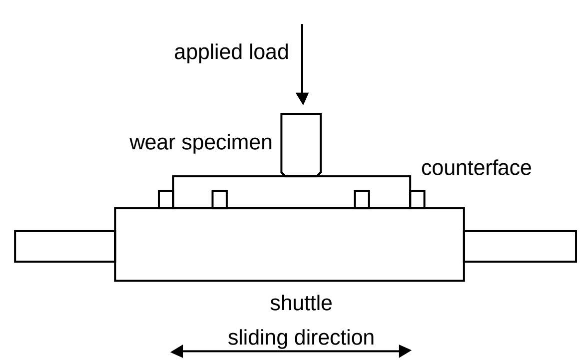

Fig. 1. Schematic representation of a reciprocating wear tester.