FRICTION AND WEAR OF ENGINEERING POLYMERS : STUDIES ON POLYIMIDES/COMPOSITES

By

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CERTIFICATE

This is to certify that the thesis "**FRICTION AND WEAR OF ENGINEERING POLYMERS : STUDIES ON POLYIMIDES/COMPOSITES**" being submitted by **Mrs. Jayshree Bijwe** to the Indian Institute of Technology,Delhi for the award of Degree of Doctor of Philosophy, is a record of bonafide research work carried out by her under our guidance and supervision. To our knowledge, it has reached the standard of fulfilling requirements of the degree. The matter embodied in this thesis has not been submitted for the award of any degree or diploma of any other University or Institute.

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ABSTRACT

Engineering polymers form one of the most important class of tribo-materials because of their excellent property profile such as self lubricity, low density corrosion and impact resistance, vibration and noise absorption, ease in processing, better wear and antiwelding characteristics. Thermoplastics are a better choice than thermosets because of special features such as higher impact resistance and interlaminar fracture toughness, ease and speed in processing, repairs and recyclability. Further, use of short fibre reinforced thermoplastics (FRPs) for tribo-applications is a fast emerging area, because of their high specific stress, stiffness and possibility of tailoring their properties through control of fibre and matrix combination.

Most of the tribo-applications demand materials which can dependably perform at elevated temperatures and have better load carrying capacity besides improved friction and wear properties. Polyimides form excellent class of such materials and their potential for tribo-applications is worth exploring.

In the light of the above, a thermoplastic polyimide, commercially known as ULTEM polyetherimide (PEI) and its various composites having very good property profile were

selected for the present studies. Since the details on the constituents of the composites were not available, these were analysed in the laboratory by various techniques. It was seen that the composites contained glass fibre reinforcement, and various solid lubricant additives, viz. polytetrafluoroethylene, MoS_2 and graphite. It was of interest to study the effect of these fillers and reinforcement on the friction and wear properties of PEI, since filler effect in tribology is not always predictable. It was worthwhile to compare tribological properties of PEI and its composites with those of commercially established thermosetting polyimide. Hence, thermosetting polyimide, commercially known as Vespel PI and its various composites were selected for the studies. The friction and wear studies were performed by sliding polymer pins against smooth metallic discs under different conditions such as varying load, sliding distance, speed, counterface roughness and fibre orientation.

It was of interest to investigate the effect of fillers and/or fibres on the wear in the abrasive condition also, since fillers affect the abrasive wear phenomenon in a complex way which cannot be predicted apriori. Hence, abrasive wear studies of various composites of PEI and PI (including bulk polymers) were performed under various abrading conditions of load, abrading particle size, distance and fibre orientation. The studies in singlepass condition were done to investigate the relationship between wear performance and appropriate mechanical properties. Studies in multipass conditions were done to see the effect of clogging of the counterface by the fillers and insitu solid lubrication under extreme abrasive conditions.

In the case of materials sliding against metal discs (adhesive transfer conditions) it was observed that PEI, a glassy yet ductile polymer does not wear by film transfer mechanism. Fatigue was seen to be the predominant wear mode. The existence of an incubation period (cycles of sliding required to generate wear particles) indicated that it has good fatigue wear resistance in the selected conditions of experiment. However, once the wear started wear rate was high ($\approx 10^{-13}$ m^3/Nm). Its PTFE filled composite showed film transfer due to PTFE. The friction coefficient exhibited by the composite was lowest amongst all the materials tested. However, wear rate was still high ($\approx 10^{-14}$ m^3/Nm). With the incorporation of glass fibres (GF) wear rate reduced dramatically (4.5×10^{-15} m^3/Nm). However, friction coefficient was highest. Inclusion of graphite along with GF resulted in a decrease in friction as well as lower wear rate (1.2×10^{-15} m^3/Nm). Addition of three solid lubricants (PTFE, graphite, and MoS_2) along with fibre reinforcement (GF), ultimately resulted in a good combination of friction and wear ($\mu \simeq 0.12$ and wear rate 8×10^{-16} m^3/Nm). The comparison of this composite of PEI with that of PI revealed that friction and wear properties of both were comparable. Although PI composite was slightly better, ($\mu \simeq 0.1$ and wear rate 5×10^{-16} m^3/Nm), ease in processing and lower cost were the two benefits associated with the thermoplastic (PEI).

The abrasive wear studies of selected materials revealed that PEI was better in this respect than PI. However, almost all the composites exhibited higher wear rates than their parent polymers. This was attributed to the reduction in Se factor where S and e are rupture stress and elongation to break. Size effect was observed in most of the materials. It is possibly due to a transition between delamination and cutting wear at a critical grit size The abrasive wear performance of these materials strongly depended on the experimental conditions. Solid lubricants effectively reduced the abrasivity of the abrasive papers reducing further wear. Thus, it was seen that the composites which performed very well in adhesive wear contidions did not perform so well in abrasive wear conditions.

Scanning electron microscopy and energy dispersive X-ray analysis were found to be very effective techniques for investigating wear mechanisms.

Abbreviations

FRPs	Fibre reinforced plastics
PTFE	Polytetrafluoroethylene
PEEK	Polyether-ether ketone
PEK	Polyether ketone
PE	Polyethylene
LDPE	Low density polyethylene
HDPE	High density polyethylene
UHMWPE	Ultrahigh molecular weight polyethylene
PA	Polyamide (nylon)
PC	Polycarbonate
PI	Polyimide
PAI	Polyamide-imide copolymer
PEI	Polyetherimide
BM	Bismalemide
PPS	Polyphenylene sulphide
POM	Polyoxymethylene (Acetal)
PU	Polyurethane
PS	Polystyrene
PMMA	Polymethyl methacrylate
PET	Poly ethylene terephthalate
PBTP	Poly butylene terephthalate
Pc	Phthalocyanine
PVC	Poly vinyl chloride
PP	PolyPropylene
EP	Epoxy resin
ABS	Acrylonitrile butadiene styrene copolymer

LCP	Liquid crystalline polymer
M S	Mild steel
GF	Glass fibre
CF	Carbon fibres
AF	Aramide fibres
Fp	Fibres parallel to the sliding surface
F_N	Fibres normal to the sliding surface
μ	Friction coefficient
μ_i	Initial friction coefficient
μ_s	Stable friction coefficient
μ_p	Peak friction coefficient
K_o	Specific wear rate
S	Stress before rupture (ultimate tensile strength)
e	elongation before rupture (ultimate tensile elongation)
H	Hardness.

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