ABSTRACT

Polymers and composites are irreplaceable tribo-materials for engineering applications. Their tribological applications include gears, a range of bearings, bearing cages, artificial human joint bearing surfaces, bearings for space applications, tires, shoe soles, automobile brake pads, non-stick frying pans, floorings and various types of surfaces for optimum tactile properties such as fibres etc. One of the major areas is of dry bearings which do not need oil/grease for lubrication. Polymeric bearings are generally used under low PV (<1 MPa m/s) conditions since they cannot sustain high frictional heat.

Research efforts are continuously being focussed to develop polymer composites which will have high PV limit values (capability to work under harsher conditions) along with low coefficient of friction and wear rate. The thesis focusses on development of several series of composites based on PAEK (Poly aryl ether ketone) as a matrix, short glass fibers (SGF) as reinforcement and combination of various solid lubricants in nano and micron sizes. Almost forty composites were characterized for physical, mechanical, thermal, thermo-physical and tribological properties. Various techniques such as SEM-EDAX (Scanning electron microscopy) (Energy dispersive-ray), XPS (X-ray photoelectron spectroscopy), Tomography, Micro-Raman spectroscopy were used for worn surface analysis. Based on best performing compositions bearings were developed, tribo-evaluated followed by design modification.

It is composed of ten chapters. Each chapter starts with introduction on the theme of the topic, followed by results, discussions and summary of work.

Chapter 1 elaborates on the introduction to the tribology of polymers and composites and the issues related to the limitations associated with the polymers and necessity for developing composites. It further continues with the role of solid lubricants in tribo-composites, polymeric
dry bearings followed by the literature survey in typical areas leading to research gaps, objectives and implementation of work plan.

Chapter 2 provides literature survey on tribology of PAEK (Poly aryl ether ketone) and composite, tribology of polymer composites explored for severe operating conditions leading to $PV_{\text{limit}}$ values and tribology of polymeric bearings.

Chapter 3 explains the details of materials procured for developing the proposed composites followed by detailing of processes employed for developing series of composites, nano-composites and bearings. The chapter further elaborates on various characterization (physical, thermal, mechanical, microscopic and spectroscopic) techniques apart from tribological in adhesive wear mode.

Chapter 4 focusses on the effect of contents of glass fiber reinforcement on the mechanical, thermal and tribological performance. 30 wt. % of fiber inclusion proved to be a better choice rather than 40 wt. % fibers for enhancing the tribo-performance at the cost of small loss in some mechanical properties.

Chapter 5 explores the effect of size of graphite particles followed by the investigations on the amount of graphite particles on the tribo-performance of polymer composite. PAEK composites showed a decrease in the $\mu$ and $K_0$ with the addition of graphite particles, a primary lubricant. Lower the size of graphite particles, better was the tribo-performance of a composite. 15 wt. % of graphite showed the best tribo-performance.

Chapter 6 explores the potential of potassium titanate (KT) particles in polymer composites followed by mechanical, thermal and tribological analysis of micro and nano-composites of KT. Nano-composite showed higher performance than the micro-composite. The nano-composite sustained very high PV value (154 MPa m/s) compared to the micro-composites (105 MPa m/s).
Chapter 7 focusses on the effect of addition of thermally conducting fillers and fibers to the tribological performance of polymer composites. It was concluded that good mechanical properties and good thermal conductivity and diffusivity were not the only parameters that totally control the tribo-performance. Other parameter like capability of thin uniform transfer film formation on the counterface had significant effect on controlling tribo-performance.

Chapter 8 focusses on investigating comparative aspects of potential of particulate secondary solid lubricants such as boric acid, hexa boron nitride, mica, MoS$_2$, WS$_2$ and PTFE in PAEK composites with identical compositions (PAEK 50 wt. %, SGF 30 wt. %, and primary solid lubricant graphite 10 wt. %). Main aim was to investigate, if any synergism exists in the functioning of two types of solid lubricants. It is divided in five major sections. Each section also highlights the influence of size of secondary solid lubricants (nano and micro). Moreover, it compares the performance of the typical composites with a standard one, which contained 10 % graphite as primary solid lubricant and 10 % as secondary solid lubricants. Among the developed composites, the composite containing short glass fibers, graphite as a primary solid lubricants and PTFE particles as secondary solid lubricant proved to be excellent tribo-composite having very low wear rate ($1.33 \times 10^{-16}$ m$^3$/Nm), low friction 0.033 and high PV$_{safe}$ (182 MPa m/s) and PV$_{limit}$ (196 MPa m/s) values. Failure mechanisms were studied using scanning electron microscopy, energy dispersive X-ray analysis, Micro-Raman Spectroscopy and X-ray photo-electron-spectroscopy.

Chapter 9 explains tribo-mechanisms of composites in material form (pin on disc configuration) and in a component form (bearings). It then justifies the selecting of few formulations for developing and performance evaluation of bearings. It contains two major sections; the first pertains to the development of thick bearings without metallic backing while the second is devoted to thin bearings with metallic backing. The chapter elaborates on the tribo-evaluation of these bearings followed by conclusions. There was a drastic difference in
the performance of materials in pin on disc configuration and component (bearing). It could be due to higher heat generation at the interface and lesser dissipation due to low thermal conductivity of material. Hence, metal backed polymer bearings were developed in order to have better thermal conductivity and thermal diffusivity property, which proved successful. Out of all developed metal backed bearings, tribo - performance of bearing with graphite and PTFE-based composite was best followed by 15 wt. % graphite-based bearings. Metal backed bearings showed significantly improved in performance compared to without metal backing with $\text{PV}_{\text{limit}}$ 2.25 MPa m/s, $K_0$ $(1.1 \times 10^{-15} \text{ m}^3/\text{Nm})$ and $\mu$ (0.02).

**Chapter 10** is the concluding chapter, with conclusions on the whole work and overall comments along with scope for future work.

*Keywords: Tribology, bearing, PAEK, PV values*