SYNOPSIS

The study of wear of polymers in general and polymer-based systems in particular is finding increasing citations in literature due to the availability of wider choice of materials, ease of manufacturing, good strength and light weight. An area where there use has been found to be very effective is the situations involving sliding contact wear. The polymer-based materials are preferred in recent years over metal-based counterparts in view of their low coefficient of friction and ability to sustain loads. This has given an impetus to industrial production of the materials, as for instance in the production of bearing components used in automobile industries such as gears, cams, wheels etc. The introduction of fibres as reinforcing agents and fillers in polymer based materials widen the scope of structural application in view of their processing useful properties like tensile strength, flexural modulus and impact strength in addition to the lightweight. However, the deployment of these as components for use in actual service requires good understanding of the processing related structure and its influence on wear. In general, the studies related to effect of fibre/filler reinforcement on the tribological behaviour of polymer composites somewhat scanty and the previous research in this area has not been extensive. Most of the research work to assess the performance of these materials has identified abrasive wear as one of the major wear mechanism. Hence, this kind of research works having a wide range of industrial or commercial importance.

The commonly used materials for reducing friction and wear are metals and its alloys, ceramics, solid lubricants, polymers and their composites. Among these composites, many are transversely isotropic in nature such as bidirectional plain weave woven fibre-reinforced polymer composites and the others are organic and inorganic particulate fillers. The mechanical properties of common polymers when compared to metals are, however, not very good and are inadequate for many structural applications. In particular, their strength and stiffness are low compared with metals and ceramics. This means that there is a considerable benefit to be gained by reinforcing polymers with fibres or fillers. Polymer matrix composites have particularly attracted a wider usage and lot of interest because of their relative ease of processing, low density, desirable electrical and thermal properties and excellent chemical and corrosion resistance.

Fillers are materials often added to polymers to improve tensile and compressive strength, tribological characteristics and dimensional and thermal stability. A wide range of fillers are used starting from non-metallic fillers like molybdenum disulphide, graphite and carbon black are some of the commonly used fillers.

However, the use of polymeric composites is still limited by tribological performance,
requiring metal inserts or other provisions, which usually negate most of the weight and fabrication benefits gained by using the composite. It is possible that with a better understanding of the tribological properties of composites they can be designed intelligently to overcome these difficulties. Numerous studies over the past few decades have investigated the tribological properties of many types of polymer composites. The effects of matrix type, fiber/filler type, fiber orientation, load, speed, lubrication, and lubricating fillers have been experimentally studied and modeled.

The objectives of the present research investigation is to study the effect of solid lubricants such as PTFE, MoS$_2$, ultra high molecular weight polyethylene (UHMWPE) and graphite on the performance of engineering plastic composites such as nylon 66, nylon 6, polycarbonate (PC) and polypropylene (PP). Addition of fillers/additives/reinforcements will affect the friction and wear properties of engineering plastics the effect needs to be clearly understood for better utilization and widening applications of engineering plastics (nylons, PP and PC) based polymer composites. This thesis focuses on the tribo-behaviours of anti-wear additives filled nylon 66, nylon 6, PP and PC composites. The wear mechanisms of these polymers are discussed. Also to generate the wealth of data on sliding wear characteristics of thermoplastic composites for the benefit of young academicians and researchers.

The research investigation titled, “Investigations on mechanical, Tribological and morphological behaviour of Polymer composites”, encompass the results of detailed investigations on mechanical, thermal and sliding wear characteristics of nylon 66, nylon 6 and PC composites with different antiwear additives/solid lubricants. The thesis has been divided into ten chapters and the contents of each chapter are briefly highlighted below.

Chapter 1 deals with the general introduction to polymer composites, fundamentals of tribology, wear behaviours, tribological behaviours of polymer composites, factors influencing on the wear behaviour and literature survey are briefly outlined. The scope of the present investigation, background and motivation of the investigation, objectives of this study and present research problem are also dealt in this chapter.

Chapter 2 describes the experimental procedures, methods and standard specifications adopted in the present research investigation. The chapter is dealt in two parts; Part A deals with the various materials such as nylon 66, nylon 6, PTFE, PC, PP, UHMWPE, MoS$_2$, glass fibre, graphite powder, carbon black and nanoclay. The different testing equipments such as UTM, hardness testing machine, impact tester, TGA, DSC, DMA, SEM, LASER, Surf test and optical metallurgical microscope are explained with manufacturer’s specifications. Part B deals with the theory, experimental procedures and techniques adopted in the present research work.
Chapter 3 covers the methods in fabrication of composites of nylon 66 and polytetrafluoroethylene (PTFE) powder in different compositions viz., 100/0, 99/1, 90/10, 85/15 and 80/20 (by wt/wt, % of nylon66/PTFE) by melt mixing using a co-rotating intermesh twin-screw extruder mixer. The effect of PTFE content on the physico-mechanical and thermal behaviors of nylon66/PTFE has been studied. The density values of all these composites were measured and found to be lies in the range between those of virgin polymers. The theoretical densities of all these composites were calculated by the volume additivity principle and correlated with the experimental densities. This correlation indicates that there is a partial interfacial attraction or incompatibility among the constituents. A slight improvement in the impact strength was noticed after incorporation of PTFE and it lies in the range 33.2-37.3 J/m. The thermal characteristics of nylon 66/PTFE composites have been performed using DSC, TGA and DMA. DSC thermograms showed that PTFE had no significant effect on the melting temperature ($T_m$), heat of melting ($\Delta H_m$) and percent of crystallinity of nylon 66. Sliding wear experiments were conducted using a pin-on-disc wear tester under dry contact condition. The effect of PTFE content, loads, sliding velocities and sliding distances on wear loss, specific wear rate and coefficient of friction of composites have been evaluated. Worn surfaces were examined with optical microscope images to have better insight of the wear mechanism. The effect of PTFE content and power of laser etching on the laser etched composite surfaces has been studied. The etched surfaces were characterized for surface roughness in z-direction and optical microscopy.

Chapter 4 deals with the fabrication and characterization of 2 wt.% graphite (Gr) filled nylon66/PTFE composites. Nylon 66 containing 2 wt % of Gr powder was extruded with 0, 5, 10, 15 and 20 wt % PTFE powder in a co-rotating twin screw extruder. The fabricated nylon 66/PTFE/Gr composites have been evaluated for physico-mechanical properties such as density, tensile behaviours, impact strength, water absorption and void content. The tensile strength decreased from 75 to 66 MPa, tensile modulus decreased from 2739 to 2672 MPa and tensile elongation decreased from 19.5 % to 14.5 % with increase in PTFE content from 0 to 20 wt%. The tensile strength decreased because the presence of soft and friction less PTFE filler in-between the nylon 66 molecular layers, does not resist tensile (stretching) force, but assist stretching, so, reduction in tensile strength and percentage elongation at break. The thermal characteristics of the composites have been studied by using DSC, DMA and TGA. The effect of PTFE content, loads, sliding velocities and sliding distances on wear characteristics of the composites were evaluated using pin-on-disc equipment. Worn surfaces were examined with
SEM to have better insight of the wear mechanism. The wear resistance of resultant nylon 66/PTFE/Gr composite increased with increase in PTFE content, but decreased with increase in load or sliding distances. Similarly the specific wear rate of nylon 66/PTFE/Gr decreased with increase in PTFE content, load and sliding distances. The co-efficient of friction decreased with increase in PTFE content. It was observed that the PTFE played a main role in the tensile resistant and wear resistant properties of nylon 66 composites. The effect of filler loading on laser etching of the polymer composites has been studied.

Chapter 5 describes the study of the effect of molybdenum disulphide (MoS$_2$) content on the nylon 66/1 wt % carbon black (CB) composites. Nylon 66/1 wt % CB composites have been compounded with different weight fractions of MoS$_2$ viz., 0.5, 1.0, 2.0 and 3.0 wt %. The fabricated MoS$_2$ filled composites have been characterized by physico–mechanical, thermal, tribological and morphological behaviours. Tensile strength of nylon 66/CB/MoS$_2$ composites increases from 64 MPa to 72 MPa on increasing the MoS$_2$ content from 0 to 3.0 wt %. Thermal characteristics of the composites have been measured using DSC, TGA and DMA. A slight improvement in thermal stability was noticed for MoS$_2$ loaded specimens. The nylon 66/CB/MoS$_2$ composites are thermally stable up to 255 ºC and completely degraded above 520 ºC. The dry sliding wear behaviour of nylon 66/CB/MoS$_2$ composites has been investigated using a pin-on-disc wear tester under dry contact condition. Specific wear rate and coefficient of friction as a function of applied normal load and sliding distance were determined. The higher wear loss was noticed for higher load and sliding distance. The sequence of coefficients of friction and wear rate of the composites is; nylon 66/CB/MoS$_2$ < nylon 66/CB < pristine nylon 66. Wear mechanisms of the composites were established using SEM. MoS$_2$ could increase the adhesion between the transfer film and the counterface surface. The ability of the synergistic fillers in helping the formation of thin, uniform and continuous transfer film would contribute to the increase in wear resistance of nylon 66 composites. The laser etching behaviour of the composites were reported by using optical microscopy and surface roughness.

Chapter 6 deals with the effects of MoS$_2$ as a filler on the physico-mechanical and wear characteristics of nylon 6/carbon black (CB)composites. Nylon 6 containing one wt % of CB powder was extruded with 0, 0.5, 1.0, 2.0 and 3.0 wt. % of MoS$_2$ in a co-rotating twin screw extruder. The fabricated composites were performed for physico-mechanical properties such as water uptake, density, surface hardness, tensile strength and impact strength. The thermal characteristics of the composites have been studied by using DSC, TGA and DMA. The effect of MoS$_2$ content, loads, sliding velocities and sliding distances on wear characteristics of the composites have been evaluated by using pin-on-disc equipment. The nylon 6/CB/MoS$_2$
composites showed enhanced wear resistance and reduced friction along with improvement in tensile strength, while the impact strength in reduced from 36.5 to 32.90 J/m. The worn surface features were studied using SEM to give insight into the wear mechanisms. It was observed that the MoS$_2$ played a main role in the tensile resistant and wear resistant properties of nylon 6 composites, while retaining its impact properties. Better laser etching resistance was noticed for the composites with MoS$_2$.

Chapter 7 deals with the effect of silane coated short glass fibres (SGF) in the presence of MoS$_2$ on nylon 66 composites. Nylon 66 was compounded with chopped strand SGF and MoS$_2$ in a co-rotating twin screw extruder. The fabricated nylon 66/MoS$_2$/SGF composites were performed for physico-mechanical, thermal, sliding wear and morphological behaviours. Addition of short glass fibre significantly improves the strength and modulus of composites. The wear behaviour of nylon 66/MoS$_2$/SGF composites were investigated under dry sliding conditions at different normal loads, sliding distances and sliding velocities at room temperature. Additional techniques such as SEM were performed to assist in data interpretation. The presence of fibre and filler affects on the wear resistance of nylon 66 matrix composites. The formation and stability of the transfer films affects the wear resistance. Glass fibre reinforced nylon 66 with MoS$_2$ filler exhibited the lowest wear rate among the materials investigated. Abrasive wear and laser etching mechanisms were observed in polymer matrix composites by using SEM and optical microscopy.

Chapter 8 describes the effect of MoS$_2$ as solid lubricant and filler on the PC/carbon black(CB) composites. PC containing one wt % of CB was compounded and extruded with 0, 0.5, 1.0, 2.0 and 3.0 wt. % of MoS$_2$ in a co-rotating twin screw extruder. The composites characterized for physico-mechanical properties such as density, void content, surface hardness, tensile behaviors and impact strength. The measured tensile data indicates that tensile strength increased from 66.6 to 67.6 MPa and tensile elongation decreased from 71.0 % to 33.8 % with increase in MoS$_2$ content from 0 to 3 wt %. The tensile modulus which is indicating stiffness variation of the material has increased from 2349 to 2369 MPa. The marginal improvement in tensile strength and tensile modulus reveals a positive interaction between the carboxyl groups of PC and sulphide layers of MoS$_2$, even though MoS$_2$ has weak Vander Waal’s interaction between the sheets of sulphide atoms. The thermal characteristics of the composites have been studied by DSC, TGA and DMA. The effect of MoS$_2$ content, loads, sliding velocities and sliding distances on wear characteristics of the composites were evaluated using pin-on-disc equipment. The PC/CB/MoS$_2$ composites showed enhanced resistance to wear and coefficient of friction with increase in MoS$_2$ content along with improvement in tensile and impact properties. It was found
that wear performance was greatly influenced by MoS$_2$, the wear characteristics strongly depends on MoS$_2$ content. Worn surfaces were examined with SEM to have better insight of the wear mechanism. It was observed that the MoS$_2$ as solid lubricant played major role in improving resistance to wear and friction.

**Chapter 9** deals with the sliding wear behaviour of polypropylene/ultrahigh molecular weight polyethylene (PP/UHMWPE, 90/10) blend loaded with 30% carbon short fibres (CSF) as reinforcement and nanoclay (NC) as filler material. The nanocomposites have been prepared by melt mixing using extruder with varying amounts viz., 0, 1, 2 and 3 wt % of NC. The thermal characteristics by DSC and TGA have been performed. Sliding wear loss, specific wear rate and coefficient of friction were investigated by using a computerized pin-on-disc machine at normal applied loads of 20, 30 and 40 N; at a sliding velocity of 1.5 m/s and at two abrading distances viz., 200 and 300 m. Worn surfaces were examined with SEM to probe the wear mechanism.

Finally conclusions of these research investigations are briefly highlighted and summarized at the end of each chapter and also references are cited at the end of each chapter. Furthermore summary and scope for further research is also highlighted in **chapter 10**.


**LIST OF PUBLICATIONS**

(a) Papers Published in International Journal


(b) Papers presented in national/international conferences


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