# Mechanical and Tribological Performance of Polymer Composite Materials: A Review

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**Abstract—**This paper reviews the effects of various reinforcements with the various thermoplastic polymer matrices. The articles contain the various thermoplastic polymers such as ABS, HDPE, LDPE, PP, PEEK, PC, PA, PI, UHMWPE and PMMA etc. The review contains the evaluation of tribological properties such as sliding wear and coefficient of friction (COF) of polymer matrix composites (PMCs). This review also evaluation of mechanical properties such as tensile strength, compressive strength, young modulus and hardness of polymer matrix composites (PMCs). The thermoplastic polymer composite used in various applications such as automotive industry, food processing machine industry, household appliance, military, structural and aerospace industry etc. The properties of thermoplastic polymer composite are varying with the fabrication techniques of composite.
**Keywords—**Polymer matrix composites, Thermoplastics polymers, Tribological properties, Mechanical properties.

## 1. INTRODUCTION

The pure polymer have replaced by the reinforcement filled polymers is called polymer composites. The polymer matrix composites (PMCs) are very useful in the field of automotive industry, food processing machine industry, household appliance, military, structural and aerospace industry etc. The thermosetting polymers are very useful due to light in weight, corrosive resistance, high wear resistance, high mechanical strength and low coefficient of friction (COF). The thermosetting polymers such as ABS, HDPE, LDPE, PP, PEEK, PC, PI, UHMWPE and PMMA etc. are very important polymer for the desired properties. The micro and nano filler such as glass fiber, graphene sheet, SWCNT, MWCNT, silicon carbide, silicon nitride, aluminum nitride, short carbon fiber (SCF), short glass fiber (SGF), clay, silica and jute fiber are very dominant reinforcement to improve the properties of polymer composites. The common abbreviations have been seen in this article; PMC-Polymer Matrix Composite, COF- Coefficient of Friction, RSM- Response Surface Methodology, ANN-Artificial Neural Network, ANOVA- Analysis of Variance, UHMWPE- Ultra High Molecular Weight Polyethylene, PTFE- Polytetrafluoroethylene, PEEK- Poly Ether Ether Ketone, SCF- Short Carbon Fiber.

The review article has been explained according to the following information about the polymer composites.

- On the tribological properties of polymer composite
- On the mechanical properties of polymer composite
- On the fabrication methods of polymer composite
- On the thermal and thermo mechanical properties of polymer composite
- On the optimization techniques

### 1.1 On the tribological properties of polymer composite

The tribological characteristics of the thermoplastic polymer composites such as high sliding wear resistance and low coefficient of friction are depends on the operating parameters likes applied load, sliding speed, distance, temperature and time. The tribological characteristics of the polymer composites are investigated by many researchers like Zhai et al. [1] discussed about the carbon material in tribology applications. The polystyrene was used as a polymer matrix. The multi wall carbon nano tube (MWCNT), nanodiamond and graphene were used as filler. Thereduced coefficient of friction (COF) was 0.004 to 0.015 under the 100 to 1200 N. Maksimkin et al. [2] studied about the comparative analysis of tribology property of canine joint and

UHMWPE material. The polymer material UHMWPE was used with 1wt % of florescent multiwall carbon nano tube (FMCNT). The coefficient of friction of cartilage was 0.026 and 0.010 after 4 km run of knee and shoulder joints respectively.

Pan et al. [3] studied about the tribology characteristics of polyimide composite. The micro particle size of lanthanum dioxide ($La_2O_3$) with 1.5 wt. % and isopropyl used as a reinforcement material. The results concluded that the COF was reduced 70% by adding $La_2O_3$ with 1.5 wt %. The COF reduced 0.4 to 0.27 but the COF of La-PI-CS increased from 0.06 to 0.08. Li et al. [4] discussed about the triboligicalbheviour of polymer composite with graphene. The material NBR was used as polymer matrix. The pristine graphene (PG) and hydroxyl functionalized graphene (HOGF) used as a reinforcement material. The two molecularmodeleswere designed as pristine graphene (PG) and HOGF with polymer. It observed that the abrasion rate was also decreased. Kumar et al. [5] discussed about the abrasive wear resistance property of UHMWPE polymer material. The composite was fabricated by using ultra high molecular weight polyethylene as a polymer matrix. The powder of aluminum nitride ($Al_2O_3$), titanium nitride and silicon nitride were used as reinforcement with size of 22 µm, 17µm and 35 µm respectively.

Tharajak et al. [6] discussed about the COF and wear property of PEEK coating with h-BN on steel disc. The poly ether ether ketone (PEEK) was used as polymer matrix. The h-BN powder was used as reinforcement with the particle size 0.5 µm and added with 2 wt. % for the improvement of wear resistance and low COF. Villaviceneio et al. [7] studied about the self lubricating properties of the composite bearing. The results showed that the tribological properties vary with the size of fiber. The tribological behavior of composite can be predicted by the DEM approach. Li et al. [8] discussed about the friction and wear property by assembly of two PEEK composite. The PEEK was used as polymer matrix. The tribological performance of the hybrid composite was also good. Masood et al. [9] discussed about the abrasion wear resistance of super hydrophobic high impact polystyrene (HIPS). The HIPS, Perfluorinated acrylic copolymer (PFAC), trifluroacetic acid (TFA) chloroform and acetone were used as polymer matrix. The silica and aerosol were used as filler with 7-40 nm in size. The coating of the composite also showed the low coefficient of friction (COF).

### 1.2 On the mechanical properties of polymer composite

The mechanical properties of the thermoplastic polymer composites such as young modulus, tensile strength, flexural strength, impact strength and hardness etc. are depend on the size, shape, wt. % and percentage of reinforcement. The mechanical properties are investigated by many researchers like Chich et al. [10] discussed about the mechanical properties of UHMWPE composite. The results concluded that the mechanical properties were improved by addition of the filler. The surface modulus and hardness were improved by 10 % and 30% by adding 2-5 wt. % of graphene nano filler (GNP).

Yurddaskal et al. [11] reported about the role of halogen free particles on the structural, mechanical and thermal characteristics of polymer composite. The polypropylene (PP) was used as a polymer composite. The huntite / hundromagnesticbentonite , antimony trioxide and zinc borate were used as a nano filler. The huntite was used as the 60 % of weight. Zhao et al. [12]studied about the mechanical property of polyamide (PI) and nano $SiO_2$ composite. The results concluded that the compressive strength was improved about 42.6 % with 5-20 wt. % nano $SiO_2$ for the composite material. Zhang et al. [13] studied about the mechanical performance of polymer composite. The polymer composite was fabricated by using ultra high molecular weight polyethylene with the $TiH_2$ and Al. The results concluded that the addition of $Ti_3C_2$, mechanical properties was improved of UHMWPE composite. The plowing and plastic deformations were also decreased by increase in hardness and mechanical characteristics of the polymer composite.

Wang et al. [14]studied about the mechanical behavior of polyimide composite with foamed cooper. The results concluded that the hardness and bending strength were improved by addition of filler material. Kawaz et al [15] discussed about the mechanical properties of acrylaic based Poly (methyl methacrylate) (PMMA) polymer with MWCNT. The results revealed that the young modulus was improved of PMMA/MWCNT composite than the pure PMMA. Kumar et al. [16] reported about the mechanical properties of ultra-high molecular-weight polyethylene (UHMWPE) composite with CNT. The higher mechanical properties of composite showed due to the high surface to volume ratio and higher interfacial bonding.

### 1.3 On the fabrication methods of polymer composite

The tribological and mechanical property of the thermoplastic composite are depends on the fabrication techniques of the composite. The thermoplastic polymer composites are fabricated according to its applications such as automotive, aerospace and structural. The various fabrication techniques for the fabrication of composites are reviewed by many researchers like Qi et al. [17] studied about the comparative study of polyimide composite against carbon steel and NiCrBSi. The friction test was performed by pin on disc (POD) test rig at room temperature. The conclusions of this paper were the COF and wear rate decrease of PI composite under sliding condition. Zhang et al. [18] studied about the effect of reinforcement with POM material in the structural and tribological applications. The results concluded that the COF was decrease by addition of AP. The COF was reduced by adding SCF into POM but wear rate ($W_S$) was increased.

Karmi et al. [19] discussed about the dry sliding charastricts of polyamide 6 with the reinforcement nano diamonds. The polyamide (PaA-6) was used as a polymer matrix with carboxylic group (ND-COOH) ND-EDA. The mechanical properties and crystalline morphology of PA 6 were improved by better dispersion of ND-EDA. The adhesive wear was important factor in this study. Zhang et al. [20] discussed about the wear resistance of PEEK filled with graphite carbon nitride. The poly ether ether ketone (PEEK) used as polymer matrix. The wear resistance is gradually increased by addition of h-CN. The value of specific wear rate was (4.0 X $10^{-7}$ $mm^3$/Nm) by the addition of h-CN with 10 vol. % in the PEEK. Golchin et al. [21] informed about the tribological characteristic of UHMWPE. The polymer composite was fabricated using UHMWPE. Subramanian et al. [22] discussed about the triboligical properties of vinyl ester polymer composite under dry sliding condition. The tribological property was also improve of the composite. Zalaznik et al. [23] discussed about the role of concentration, size and type of filler material on the tribological properties of the PEEK composite. The homogeneous mixture was pressed under disc with pressure of 100 MPa and heated at temperature of 300 ºC for 60 minutes. The result was concluded that the coefficient of friction was decreased about 30 % compared to pure PEEK. Lin et al. [24] discussed about the tribological performance under varying load condition of the PEEK composite. The results concluded that the wear properties were improved by addition of filler materials under high load condition. Song et al. [25] examined about the effect of glass fiber and $MoS_2$ powder on the trbological properties of PTFE composite. The glass fiber was also improved the tribological properties of composite. Qi et al. [26] studied about the effect of nanoparticles on the structure of polyamide composite. The wear rate of GCr15, SUS316 and Cr were also decreased by 77.3 %, 43.4 % and 70.0 % respectively. Rodriguez et al. [27] discussed about the wear behavior of PEEK based hybrid composite under sliding condition. The tribological behavior was improved by addition of nano filler having the sliding velocity 10 and 50 mm/sec with pressure 10 MPa.

### 1.4 On the thermal and thermo mechanical properties of polymer composite

The thermal and thermo mechanical characteristics such as thermal expansion, heat deflection and mass loss of the thermoplastic polymer composites are important in the various filled like as friction component and heating elements. The thermal and thermo mechanical characteristics of the thermoplastic polymer composites are discussed by researchers like Cifuentes et al. [28] discussed about the evaluation of mechanical property of PLA composite with micro particles of Mg. The DSI experiments show the good agreement by uni axial compression test. Liu et al. [29] discussed about the wear property of high- density polyethylene (HDPE) with graphitic nanoplatelet. The results concluded that wear was decreased by addition of GNP in the HDPE. The tribological property was enhanced up to 97 % at the sliding velocity 13 m/sec.

Atuanya et al. [30] discussed about the thermal and wear property of recycled low density polyethylene (RLDPE) polymer with breadfruit seed hull ash particulate (BFSHAp). The results concluded that the thermal decomposition temperature and wear rate were increased by addition of reinforcement. Qian et al. [31] discussed about the mechanical and thermal property of the polyimide polymer with functionalized graphene oxide (FGO). The TGA test was performed for evaluation of thermal stability of the polymer composite material. The temperature range was greater. Naffakh et al. [32] discussed about the mechanical, thermal and tribological property of the poly (3-hydroxybutyrate) (PHB) polymer. The TGA test was performed to evaluate the thermal property of the composite material. The weight loss $T_g$ and $T_{mr}$ were occurred at the 286 ºC to 303 ºC of the composite material. The tribological property was also improved by addition of INT-$WS_2$.

### 1.5 On the optimization techniques

The tribological and mechanical properties of the thermoplastic composites are depends on the design of experiments. The experiments are designed by input parameters such as filler %, load and speed etc. and responses like wear rate, COF, tensile strength and young modulus. The various technique such as Taguchi, RSM and ANN are discussed by researchers like Sudeepan et al. [33]discussed about the wear and friction of ABS polymer with ZnO using Taguchi technique. The optimum values of the input variables were filler content 15 wt. %, speed 120 rpm and applied load 35 N for the low wear rate. The S/N ratio was improved by 18.60 % and 14.43 % for the COF and wear rate respectively.

Dayma et al. [34]discussed about the sliding wear of PA-6/PP-g-MA polymer with nanoclay. The PA-6/PP-g-MA was used as the polymer matrix for the fabrication of polymer composite. The results concluded that the optimum process parameters were obtained for the low wear resistance. Cho et al. [35]examined about the tribological characteristics of polyphenylene sulfide polymer composite with the $MoS_2$, $SiO_2$, CuS and $Al_2O_3$ by Taguchi technique. The optimum process parameters were carried out by the Taguchi technique. Ghasemi et al. [36]evaluated about the mechanical characteristics of polypropylene polymer with talc and graphene fillers. The maximum tensile strength was carried out with the talc 27.01 wt. %, MAPP 4 wt. % and graphene 0.69 wt. %.

Fakhri et al. [37]reported about the optimization of mechanical properties of polystyrene polymer with nanoclay and nano ZnO. The ANOVA calculation showed that the all six responses were significant. Liu et al. [38]studied about the optimization of process parameters for the polysulfonamide (PSA) composites with filler of short carbon fiber (SCF). The optimum process parameters such as temperature, time and composition for the higher mechanical properties were 372.88 ºC, 29.17 min and 40 wt. % respectively.

## 2. **Conclusion**

It has been concluded in research papers that the polymer matrix composites (PMCs) are most important material for the applications in various sectors like aerospace, automotive, food processing machine and structural etc. The many researchers discussed in review articles that the thermoplastic polymer composite are made of polymer matrix with reinforcements such as $SiO_2$, $Al_2O_3$, ZnO, $Si_3N_4$, SCF, graphene, glass fibre, SWNT and MWCNT etc. in the micro or in nano size. The thermoplastic composites have some unique characteristics such as light in weight, low COF, corrosion resistance, high strength, high wear resistance and self lubricated. The binary or hybrid composites are more suitable for the low COF, high wear resistance and high mechanical properties. The mechanical properties such as young modulus, tensile strength, hardness are increased by addition of binary or hybrid reinforcement. The thermal properties such as mass loss and heat deflection are improved by addition of reinforcements. The mechanical, tribological and thermal characteristics are also varied by the fabrication techniques of the composite, size and shape of the reinforcement.

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