Composites Science and Technology

Hemalata Jena
Jitendra Kumar Katiyar
Amar Patnaik *Editors*

Tribology of Polymer and Polymer Composites for Industry 4.0

Springer

Composites Science and Technology

Series Editor

Mohammad Jawaid, Lab of Biocomposite Technology, Universiti Putra Malaysia,
INTROP, Serdang, Malaysia

Composites Science and Technology (CST) book series publishes the latest developments in the field of composite science and technology. It aims to publish cutting edge research monographs (both edited and authored volumes) comprehensively covering topics shown below:

- Composites from agricultural biomass/natural fibres include conventional composites-Plywood/MDF/Fiberboard
- Fabrication of Composites/conventional composites from biomass and natural fibers
- Utilization of biomass in polymer composites
- Wood, and Wood based materials
- Chemistry and biology of Composites and Biocomposites
- Modelling of damage of Composites and Biocomposites
- Failure Analysis of Composites and Biocomposites
- Structural Health Monitoring of Composites and Biocomposites
- Durability of Composites and Biocomposites
- Biodegradability of Composites and Biocomposites
- Thermal properties of Composites and Biocomposites
- Flammability of Composites and Biocomposites
- Tribology of Composites and Biocomposites
- Bionanocomposites and Nanocomposites
- Applications of Composites, and Biocomposites

To submit a proposal for a research monograph or have further inquries, please contact springer editor, Ramesh Premnath (ramesh.premnath@springer.com).

More information about this series at http://www.springer.com/series/16333

Hemalata Jena · Jitendra Kumar Katiyar ·
Amar Patnaik
Editors

Tribology of Polymer and Polymer Composites for Industry 4.0

Springer

Editors
Hemalata Jena
School of Mechanical Engineering
Kalinga Institute of Industrial Technology
Bhubaneswar, India

Jitendra Kumar Katiyar
Department of Mechanical Engineering
SRM Institute of Science and Technology
Chennai, Tamil Nadu, India

Amar Patnaik
Department of Mechanical Engineering
Malaviya National Institute of Technology
Jaipur
Jaipur, India

ISSN 2662-1819 ISSN 2662-1827 (electronic)
Composites Science and Technology
ISBN 978-981-16-3902-9 ISBN 978-981-16-3903-6 (eBook)
https://doi.org/10.1007/978-981-16-3903-6

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Contents

Frictional and Wear Behavior of Epoxy Resin Based Nano-Composite in Dry Sliding Contact

Avinash V. Borgaonkar and Shital B. Potdar

Abstract Recently, there has been a growing interest in polymers as well as polymer composites and their industrial demands as an efficient alternative for pure metals and hybrid materials. In the present work, tribological investigation of MoS_2 and ZrO_2 reinforced polymer nano-composites have been carried out. The effects of different wt. % of MoS_2 and ZrO_2 on the tribological properties of MoS_2 and ZrO_2 reinforced polymer nano-composites have been studied. A tribological study of the fabricated polymer nano-composites were performed using the pin-on-disc friction and wear test rig at different operating conditions (such as contact pressure and sliding speed). It was observed that MoS_2 reinforced polymer nano-composite exhibits low frictional coefficient compared to ZrO_2 reinforced polymer nano-composite. However, ZrO_2 reinforced polymer nano-composite possesses higher wear resistance compared to MoS_2 reinforced polymer nano-composite. In addition, the particle size of reinforcement material may also affect the tribological properties of the fabricated polymer nano-composites. Among all samples of MoS_2 and ZrO_2 reinforced polymer nano-composites, the samples with 15% wt. depicts the lowest friction coefficient and wear rate.

Keywords Friction · Molybdenum disulphide (MoS_2) · Polymer nano-composites · Tribological properties · Wear · Zirconium dioxide (ZrO_2)

A. V. Borgaonkar (✉)
Department of Mechanical Engineering, National Institute of Technology Warangal, Telangana Warangal-506004, India

S. B. Potdar
Department of Chemical Engineering, National Institute of Technology Warangal, Telangana Warangal-506004, India

H. Jena et al. (eds.), *Tribology of Polymer and Polymer Composites for Industry 4.0*, Composites Science and Technology, https://doi.org/10.1007/978-981-16-3903-6_1

1 Introduction

Polymers and polymer based composites have been extensively used in dry sliding applications, where external aid of lubricant is not recommended or impossible. In the recent years, the self-lubricating materials have been popularly used in tribological applications. From the past few decades, polymers and polymer composites have substituted many conventional metals for sliding components. This provides reduction in weight and enhanced corrosion resistance; at the same time improved excellent tribological properties. Based on the molecular structure the polymers are classified into three groups: thermoplastics, thermosets and elastomers. Figure 1 depicts the polymer classifications and the possible reinforcements.

Thermoplastic materials have gained importance since they possess self-lubricating properties. The polytetrafluoroethylene (PTFE) is the most widely used thermoplastic material. PTFE in combination with metals exhibits lower friction coefficient (COF) operating at high load and low sliding speed. Also PTFE has low yield strength. These advantages make PTFE as an excellent material for sliding bearings (Khedkar et al. 2002). The anti-frictional PTFE composed materials with different fillers (such as coke, soot, fibres, metal powders, graphite, molybdenum disulphide) helps to enhance the strength of the matrix polymer (Aldousiri et al. 2013). In addition, PTFE is also used as filler material to reduce COF for thermoplastic as well as thermosetting polymers. The bearing liners made of a steel substrate having top porous bronze layer impregnated with PTFE composites. These bearings are highly efficient in dry sliding conditions under high contact pressure and at lower sliding speed. Polyamides are mostly preferred for sliding bearings reinforced with fillers as well as dry lubricants. These are also used for fabricating gears as well as thin film polymer coatings. Polyformaldehyde, polyarylates and polycarbonate are also used

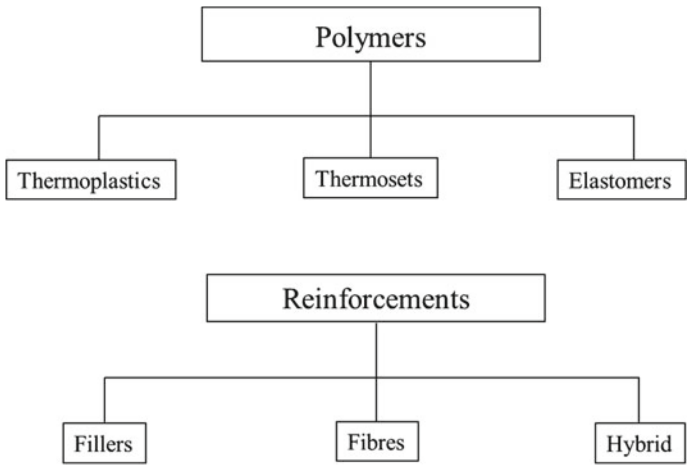


Fig. 1 Classification and reinforcement used for polymers

for manufacturing gears, bushings, and sliding bearings. Among these thermosetting polymers, polyimides sustain at a higher operating temperature (up to 260 °C). Epoxy and phenolic resin composites dispersed employing solid lubricants such as graphite or MoS_2 are often used as matrices for antifriction linings of machine guides (Ching et al. 2017). Thermosetting polymers are majorly used as base matrix materials for clutches, brakes and other frictional components. Elastomers like polyurethanes and rubbers are mainly being used as anti-abrasion linings for metallic surfaces as well as seals. The most popular application of elastomers is automotive tires (Peters 2014). The various aspects affecting the tribological properties of polymers are structure and position of macromolecules on the surface, multi-phase nature, degree of crystallinity; kind of polymers, such as homo-polymers, block copolymers, etc., composition for blends, chain orientation acquired in processing such as extrusion, molecular structure such as linear, branched or cross-linked and molecular mass distribution (Brostow et al. 2003). Samyn et al. (2007) were reviewed the tribological behavior of sintered and thermoplastic polyamides under adhesive sliding. They were reported that polyimides functions well at higher temperature. The tribological performance mainly influenced due to applied load, sliding velocity and humidity. Based on the referred literature they have developed theoretical models sintered and thermoplastic polyimides. They have observed that the tribo-chemical and tribo-physical reactions plays very important role in frictional and wear analysis of the polymers.

The different polymers and its composites have been used so far in order to study their tribological properties have been reported in this section. Sınmazcelik and Yilmaz (2007) were studied the thermal aging effects on the tribological behavior of pure poly-ether-ether-ketone (PEEK) and PEEK reinforced with random oriented short fibres. They observed that due to isothermal aging process, the degree of crystallinity is decreased considerably but at the same time well-organized crystalline structure has been achieved. The resulting trans-crystalline layer formation helps to improve its flexural modulus. Thermal aging process also influences the impact testing properties of pure PEEK and its composites dramatically. Thermal aging makes the material becomes highly brittle and also decreases the toughness remarkably. They observed that percentage (%) crystallinity is not the unique parameter which affects the polymers performance; the crystal orientation is also an important parameter which plays an outstanding role in enhancing mechanical as well as tribological properties of PEEK and its composites. The study reveals that there is a strong co-relation exists between thermal aging and micro-structure. At the same instance nonlinear relationship has been observed between its micro-structure and tribological properties. Micro-structural changes took place after thermal aging helps to improve the mechanical properties which eventually results in improved tribological properties. Burris and Sawyer (2006) were developed a PEEK filled PTFE composite with different wt. % addition of PEEK from 0 to 70%. The tribological tests were performed using a linear reciprocating tribometer against lapped steel counter-disc surface. The tests for all the samples performed at same operating conditions. The composite material exhibits a low COF and wear rate than pure PEEK and PTFE samples. The microscopic analysis shows that the interfacial connection between PTFE and PEEK significantly improves the tribological properties. The composites were prepared PEEK with wt. % of 50 and wt. % of 32 exhibiting lowest COF and wear rate respectively.

Unal (2004) and Unal et al. (2006) have performed the tribological study for the bronze filled with PTFE (25 wt. %) polymer against stainless steel counter-disc in dry sliding conditions using a pin-on-disc test rig. The tribological tests were performed under various load and speed conditions. The test results reveal that, at all sliding speeds, the COF of composite filled with PTFE decreases suddenly with rise in load, whereas the wear rate decreases linearly with the rise in the load. In addition, the wear rate was less sensitive to the speed and highly sensitive to the load, especially at higher loads. In another study Unal et al. (2010) analysed the tribological performance of pure PTFE, and PTFE +17 wt. % glass fibers reinforced (GFR). The study has shown that, the COF reduces as applied load increases. The PTFE +17 wt. % GFR exhibits higher wear resistance in comparison with pure PTFE and PTFE +35 wt. % C. The microscopic analysis showed that the wear took place by both adhesive and abrasive mechanism.

Sumer et al. (2008) analysed tribological behavior of pure PEEK and PEEK reinforced with 30 wt. % GFR under dry sliding and water lubricated conditions. The tribological tests were performed against AISI steel disc under different operating conditions (such as load and speed). For dry sliding condition, slight increase in COF and specific wear rates have been observed with increase in load for both unfilled PEEK and PEEK filled with GFR composite. Whereas, with increase in sliding speed the decrease in COF while increase in specific wear rate have been observed. In addition, under same operating parameters in case of water lubricated conditions lower values of both COF and specific wear rate have been observed compared to dry condition. The addition of glass fibres significantly improves the tribological performance of the composite under dry sliding condition. Greco et al. (2011) have evaluated the tribological properties of unfilled PEEK and PEEK reinforced using short and long woven fibres with random orientations. These polymer materials used to fabricate the disc and operated at higher sliding speed against steel balls using a 3 ball-on-flat test rig. The test results have demonstrated that composite comprised of long woven fibres exhibit the lower COF and wear rate. Yamamoto and Takashima (2002), Yamamoto and Hashimoto (2004) were investigated the tribological properties of PEEK and polyphenylenesulfide (PPS) under water lubricated condition employing a face-contact sliding tester. They have observed formation of ferrous sulphide (FeS) layer in case of PPS, on the counter steel surface due to reaction of sulphur with the steel surface. The formation of FeS layer assists for transfer/adhesion of PPS onto the counter steel surface which results into reduction in wear. However, only immersion of PEEK in water not reduces its hardness but it leads to reduce the hardness of sliding surface which promotes high wear rate.

Unal and Findik (2008) performed tribological tests of industrial polyamides (PA) against the counterbody made of different polymers in dry sliding conditions. The PA 66 polymer and PA 46 filled with 30 wt. % of GFR composite have been used in this study. The test results reveal that for these polymers the COF is decreasing with increase in load up to 40 N and above this COF is increasing. Whereas, the low wear rate was observed, for GFR reinforced PA 46 polymer composite against the same counterbody material. Author demonstrated that GFR reinforced PA 46 polymer composite was a favourable thermoplastic material for electrical contact breaker applications. Further Unal and Mimaroglu (2003), Unal et al. (2004, 2005) have extended the study for PA 66, polyoxymethylene (POM), ultrahigh molecular weight polyethylene (UHMWPE), GFR reinforced PPS and aliphatic polyketone (APK) polymers. Their study shown that, for all the considered polymers, the COF reduces in linear manner along with the increase in load, whereas the sliding velocity has significant effect on the specific wear rate of the polymers. The PA 66 exhibits lowest specific wear rate while POM exhibits highest one. Li et al. (2017) were fabricated polymer composites using nylon-6 (MC PA6) and graphene (GN) nano-composites by doping polyethylene glycol (PEG) as a compatibilizer as well as solid lubricant. The microscopic analysis showed that addition of PEG tends to superior grafting of PA6 molecules on graphene surface, while graphene was uniformly dispersed in the matrix. The experimental test results shown that in comparison with pure MC PA6, addition of 0.5 wt. % of GN enhances tensile strength by 12% while impact strength by 20.6%. The tribological test results shown that in comparison with pure MC PA6, 0.7 wt. % addition of GN reduces the COF by 13% and specific wear rate by 75%. From the microscopic analysis of worn surface it has been observed that the surface exhibits flat and smooth features with uniform distribution of graphene, and get annealed due to lower frictional heat generated at the contacting surfaces. The synergistic effect of reinforcing and lubrication of GN-PEG, helps to improve their mechanical as well as tribological properties significantly.

In order avoid the loosening of nano-particle agglomerates in polymer composites; Zhang et al. (2002) introduced an irradiation grafting method. They have fabricated composite employing covalent bonding of polyacrylamide (PAAM) onto the nano-silica. They experienced that due to grafting PAAM supports for the curing of epoxy which enhances the chemical bonding between fillers and matrix. The study showed that nano-silica/epoxy composites exhibits excellent tribological performance in comparison with pure epoxy. Further Rong et al. (2003) extended the study by introducing a chemical grafting method. They fabricated PAAM composite with doping silicon carbide, alumina and silicon nitride nano-particles. The tribological analysis reveals that the COF and specific wear rate of the developed PAAM composite are lower than that of pure epoxy. This is because of improved bond strength caused due to the enhanced interfacial interaction between filler and epoxy matrix. The COF is reduced due to production of lubricity by fine wear debris. Whereas, the improvement in the wear resistance due to increase in micro-hardness and enhanced thermal conducting capability. Yoon et al. (2006) developed patterns with different aspect ratios of polymethylmethacrylate (PMMA) on silicon wafer employing lithographic method. They investigated the tribological response of these fabricated nano-patterns with flat PMMA thin films. The test results reveal that the patterned samples demonstrated excellent tribological performance. The nano-patterned structures were exhibited superior bond strength and tribological behaviour because of their hydrophobic nature and decreased contact area. Polybenzimidazole (PBI) polymer having higher thermal stability, but due to problems related with its processing, it has not been used popularly. In order to resolve this problem, a composite of PBI and Polyetherketone

(PEK) was fabricated by Bijwe et al. (2015) and their mechanical as well as tribological properties were analysed. In addition a number of composites comprised with solid lubricants, glass fibres and carbon were fabricated. The mechanical, physical, thermal as well as tribological properties of these composites were evaluated. There is no any significant improvement has been observed in the tribological performance of composites blended with only solid lubricants or fibres. Whereas the composites containing polymers, solid lubricants, glass as well as carbon fibres, produces a remarkable improvement in the tribological properties. The developed composite demonstrated excellent tribological properties as compared with the commercially available PBI–PEEK blend composite.

Pihtili (2009) have investigated the frictional and wear properties of GFR reinforced epoxy resin and GFR reinforced polyester resin composite at different load and speed conditions by employing a block-on-shaft test rig in dry sliding condition. For all test conditions GFR reinforced epoxy resin composites demonstrated high strength and wear resistance in comparison with GFR reinforced polyester resin composites. Rong et al. (2001) developed TiO_2 nano-particles dispersed epoxy polymer composite. The tribological tests of the fabricated composites were performed against a smooth steel counterpart in dry sliding condition. The microscopic analysis showed that the homogeneous dispersion of the nano-particles enhances wear resistance. For homogeneous phase dispersion of epoxy and the nano-particles chloroform has been used and at the mixture was continuously stirred and heated unless the composite was fully cured. They concluded that the developed polymer composite exhibits excellent tribological performance compared with pure epoxy composites.

Up till now, very few studies have been reported the tribological properties of epoxy resin based nano-composites. The study in this direction is very much essential, since currently significant development is happening in the area of epoxy resin based nano-composites for current industrial applications. Hence, the objective of the present study is to investigate the tribological behavior of epoxy based nano-composites reinforced using MoS_2 and ZrO_2 nano-particles.

2 Materials and Methods

2.1 Materials

In order to fabricate polymer based nano-composites the base matrix epoxy resin and curing agent procured from Sisco Research Laboratories Pvt. Ltd., Mumbai, India. The different reinforcements materials such as MoS_2 (with average particle size 70–90 nm), ZrO_2 (with average particle size 170–200 nm) and ZrO_2 (with average particle size 90–120 nm) powders were purchased from Sisco Research Laboratories Pvt. Ltd., Mumbai, India.

2.2 *Characterization and Methods*

2.2.1 Surface Topography

The surface topography of the pin and the counter face disc surface was measured using the Surtronic S-100 (Taylor Hobson) Series Surface Roughness Tester. The required surface roughness was achieved by polishing with different grades of silicon carbide papers.

2.2.2 Pin on Disc Friction and Wear Test Rig

The tribological study of the fabricated epoxy resin based nano-composites were performed at different contact pressure and sliding speed conditions using the pin on disc test rig provided by Magnum, India. The pin is having flat end (12 mm diameter and 25 mm length), whereas the disk is made up of EN-31 steel material (165 mm diameter and thickness of 8 mm).

2.2.3 Sample Preparation

In order to prepare the epoxy based nano-composites the MoS_2 nano-particles were directly mixed with epoxy resin and the mixture was heated and kept in an oven with constant pre-set 80 °C temperature. After 30 min, the mixture was taken out of oven and stirred with magnetic stirrer for another 30 min. For uniform dispersion of nano-particles, the mixture was sonicated for 10 min. Eventually, the curing agent was poured, and the composites were cured by keeping the mixture in the oven at 80 °C temperature for 3 h. The same procedure was adopted to prepare nano-ZrO_2/epoxy composites. In order to investigate the optimum wt. % of MoS_2 and ZrO_2 into the epoxy base matrix which exhibits better tribological properties the wt. % of MoS_2 and ZrO_2 varied from 5 to 25%.

3 Experimental Testing

The experimental tests were performed at room temperature in air. The pin on disc friction-wear test rig is used in this study as depicted in Fig. 2. The stationary pin is pressed against rotating disk under the given load. The pin is cylindrical with flat end. During the test, the friction force and wear are continuously monitored. A typical friction curve measurement recorded using data acquisition system.

For obtaining reliable results each experiment was repeated three times. The test parameters employed in the experimental tests are indicated in Table 1.

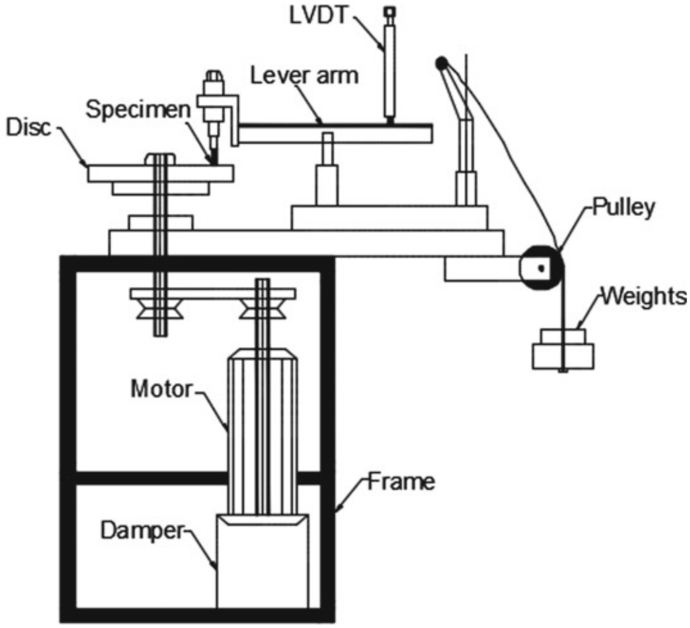


Fig. 2 Schematic set up of pin-on-disc friction and wear test rig

Table 1 Operating parameters and its ranges

Sr. No	Parameters	Operating conditions
1	Contact pressure	88, 176, 264 kPa
2	Sliding speed	1, 2, 3 m/sec
3	Track radius	40 mm
4	Sliding distance	3000 m

The composite specimens were tested using pin-on-disc test rig which consists of a pin holder sliding against a counter-disc. For minimising the running-in period time, the pin samples were pre-worn by grinding using silicon carbide (SiC) paper against the counter-disc. After polishing the surface roughness was measured at different locations using surface roughness tester. The average surface roughness value (Ra) was observed to be 0.4 μm. This helps to keep the same roughness of the samples before test as well as the parallel alignment of the two mating surfaces could be guaranteed. The counter disc steel discs surface was cleaned with acetone before service.

4 Results and Discussion

4.1 Effect of Different Reinforcement Material (MoS_2/ZrO_2) Addition on COF

The effect of reinforcement material i.e. MoS_2 addition on COF at different contact pressures and sliding speeds is shown in Fig. 3. It can be observed that the wt. % addition MoS_2, contact pressure and sliding speed shows a significant effect on the magnitude of COF.

The COF was observed to be higher for pure epoxy specimen (indicated by 0 wt. % MoS_2 addition). As the MoS_2 added into epoxy matrix the reduction in COF has been observed. MoS_2 offers low friction due to their anisotropic layered structure, i.e. covalent bonding and weak Vander Waals forces between the adjacent lamellae. With the increase in contact pressure and sliding speed the COF found to be reduced due to transfer of polymer composite film on to the counter surface. The addition of MoS_2 into the epoxy base matrix helps to reduce COF. However, the higher concentration of MoS_2 material leads to improper mixing between the reinforcement material and base matrix which results into poor bonding (Greco et al. (2011) and Rong et al. (2001)). Due to which after 15 wt. % addition the COF found to be increasing. The similar trend has been observed in case of ZrO_2 added polymer nano-composite.

The effect of reinforcement material i.e. MoS_2 and ZrO_2 addition on COF at 264 kPa contact pressure and 3 m/sec sliding speed is shown in Fig. 4. The magnitude of COF in case of ZrO_2 added polymer nano-composite found to be higher than MoS_2 added polymer nano-composite due to its particle size and hardness. The pure epoxy specimen exhibited Vickers microhardness value 123.8 ± 0.7 (MPa).

The hardness values of prepared nano-composite samples are mentioned in Table 2.

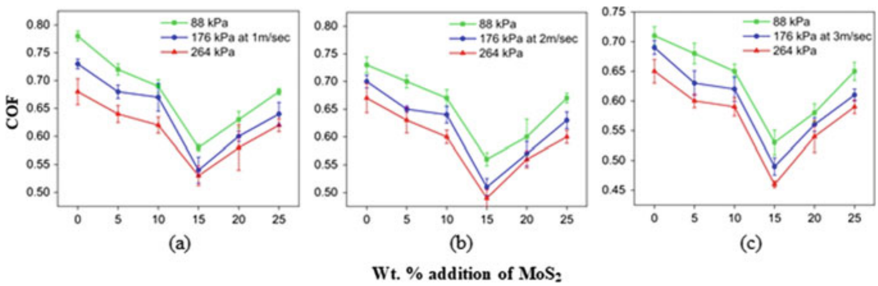


Fig. 3 COF for epoxy-MoS_2 polymer composite with different wt. % addition of MoS_2 at 88 kPa, 176 kPa, 264 kPa contact pressure **a** 1 m/sec **b** 2 m/sec **c** 3 m/sec sliding speed

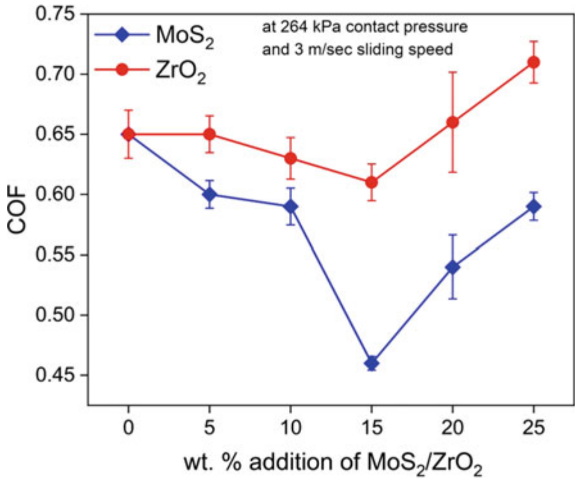


Fig. 4 COF for epoxy-MoS_2 and epoxy-ZrO_2 polymer composite at different wt. % addition of MoS_2/ZrO_2 at 264 kPa contact pressure and 3 m/sec sliding speed

Table 2 Micro-hardness values of epoxy based nano-composite specimens

Reinforcement material	HV (MPa)				
	5%	10%	15%	20%	25%
MoS_2	154.6 ± 13.2	163.2 ± 8.7	171.3 ± 11.9	166.7 ± 19.4	159.4 ± 13.5
ZrO_2	259.3 ± 5.8	273.1 ± 9.4	286.7 ± 6.9	262.6 ± 16.7	254.8 ± 3.9

4.2 *Effect of Different Reinforcement Material Addition on Wear Rate*

The effect of reinforcement material i.e. MoS_2 addition on wear rate at different contact pressures and sliding speeds is shown in Fig. 5. It can be observed that the wt. % addition MoS_2, contact pressure and sliding speed shows a remarkable effect on the magnitude of wear rate.

The wear rate was observed to be higher for pure epoxy specimen (indicated by 0 wt. % MoS_2 addition). As the MoS_2 offers low friction due to weak Vander Waals forces between the adjacent lamellae; the worn out MoS_2 particles get entrapped into asperities between the contacting surfaces. This resulted into decrease in wear rate with the addition of MoS_2 into the epoxy base matrix. However, as the concentration of MoS_2 increases; it leads to improper mixing between the reinforcement material and base matrix which results into poor bonding (Greco et al. (2011) and Zhang et al. (2002)). Due to which after 15 wt. % addition the wear found to be increasing. The similar trend has been observed in case of ZrO_2 added polymer nano-composite.

The effect of reinforcement material i.e. MoS_2 and ZrO_2 addition on wear rate at 264 kPa contact pressure and 3 m/sec sliding speed is shown in Fig. 6. The ZrO_2

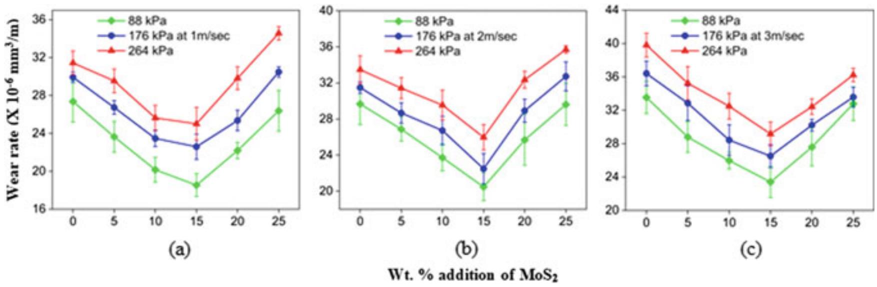
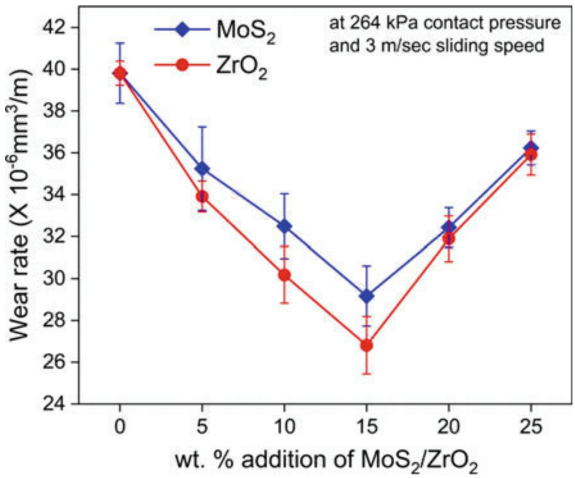


Fig. 5 Wear rate (mm^3/m) for epoxy-MoS_2 polymer composite with different wt. % addition of MoS_2 at 88 kPa, 176 kPa, 264 kPa contact pressure **a** 1 m/sec **b** 2 m/sec **c** 3 m/sec sliding speed

Fig. 6 Wear rate (mm^3/m) for epoxy-MoS_2 and epoxy-ZrO_2 polymer composite at different wt. % addition of MoS_2/ZrO_2 at 264 kPa contact pressure and 3 m/sec sliding speed



added polymer nano-composite exhibits higher wear resistance due to its higher hardness (Rong et al. (2001)).

5 Conclusion

Within the scope of this study, MoS_2 and ZrO_2 reinforced polymer nano-composites have been fabricated with different wt. % addition of reinforcing material. The frictional and wear behavior of the developed polymer nano-composites at different contact pressure and sliding speed have been investigated. The test results demonstrated that, the reinforced polymer nano-composites exhibit excellent tribological performance compared to pure epoxy composite in all considered operating conditions. The MoS_2 reinforced polymer nano-composites exhibits lower frictional coefficient due to weak Vander Waals forces between the adjacent lamellae and its easy shearing ability as reported by (Rong et al. (2001)). Whereas the ZrO_2 reinforced polymer nano-composites exhibits high wear resistance due to its higher hardness. The hardness of the ZrO2 reinforced polymer nano-composites enhanced by 54% compared to pure epoxy and 43% compared to TiO2 reinforced polymer nano-composites as reported by (Rong et al. (2001). In case of both the reinforced polymer nano-composites the sample with 15% wt. addition depicts the lowest frictional coefficient and wear rate.

6 Future Scope

Further research for the improvement of the performance of the MoS_2 and ZrO_2 reinforced polymer nano-composites is needed to explore the followings:

- Computational study of the developed reinforced polymer nano-composites can be performed for validating the experimental results.
- The tribological performance of polymers in combination with surface texturing can also be studied.

References

Aldousiri B, Shalwan A, Chin CW (2013) A review on tribological behaviour of polymeric composites and future reinforcements. Adv Mater Sci Eng 2013(1):1–8

Bijwe J, Gupta MK, Parida T, Trivedi P (2015) Design and development of advanced polymer composites as high performance tribo-materials based on blends of PEK and ABPBI. Wear 342:65–76

Brostow W, Deborde JL, Jaclewicz M, Olszynski P (2003) Tribology with emphasis on polymers: friction, scratch resistance and wear. J Mater Educ 25(4–6):119–132

Burris DL, Sawyer WG (2006) A low friction and ultra-low wear rate PEEK/PTFE composite. Wear 261(3–4):410–418

Ching YC, Chuah CH, Ching KY, Abdullah LC, Rahman A (2017) Applications of thermoplastic-based blends. In: Recent developments in polymer macro, micro and nano blends. Woodhead Publishing, pp 111–129

Greco AC, Erck R, Ajayi O, Fenske G (2011) Effect of reinforcement morphology on high-speed sliding friction and wear of PEEK polymers. Wear 271(9–10):2222–2229

Khedkar J, Negulescu I, Meletis EI (2002) Sliding wear behavior of PTFE composites. Wear 252(5–6):361–369

Li C, Xiang M, Ye L (2017) Intercalation structure and highly enhancing tribological performance of monomer casting nylon-6/graphene nano-composites. Compos A Appl Sci Manuf 95:274–285

Peters EN (2014) Thermoplastics, thermosets and elastomers-descriptions and properties. Mechanical Engineers Handbook, pp 1–48

Pihtili H (2009) An experimental investigation of wear of glass fibre–epoxy resin and glass fibre–polyester resin composite materials. Eur Polymer J 45(1):149–154

Rong MZ, Zhang MQ, Liu H, Zeng H, Wetzel B, Friedrich K (2001) Microstructure and tribological behavior of polymeric nanocomposites. Ind Lubr Tribol 53(2):72–77

Rong MZ, Zhang MQ, Shi G, Ji QL, Wetzel B, Friedrich K (2003) Graft polymerization onto inorganic nanoparticles and its effect on tribological performance improvement of polymer composites. Tribol Int 36(9):697–707

Samyn P, Schoukens G, Verpoort F, Van Craenenbroeck J, De Baets P (2007) Friction and wear mechanisms of sintered and thermoplastic polyimides under adhesive sliding. Macromol Mater Eng 292(5):523–556

Sınmazcelik T, Yilmaz T (2007) Thermal aging effects on mechanical and tribological performance of PEEK and short fiber reinforced PEEK composites. Mater Des 28(2):641–648

Sumer M, Unal H, Mimaroglu A (2008) Evaluation of tribological behavior of PEEK and glass fiber reinforced PEEK composite under dry sliding and water lubricated conditions. Wear 265:1061–1065

Unal H, Findik F (2008) Friction and wear behaviors of some industrial polyamides against different polymer counterparts under dry conditions. Industrial Lubrication and Tribology 60(4):195–200

Unal H, Mimaroglu A (2003) Friction and wear behavior of unfilled engineering thermoplastics. Mater Des 24:183–187

Unal H, Sen U, Mimaroglu A (2005) Abrasive wear behavior of polymeric materials. Mater Des 26:705–710

Unal H, Sen U, Mimaroglu A (2006) An approach to friction and wear properties of polytetrafluoroethylene composite. Mater Des 27:694–699

Unal H, Yetgin SH, Mimaroglu A, Sumer M (2010) The effect of test parameters on friction and wear performance of PTFE and PTFE composites. J Reinf Plast Comp 29(13):1978–1986

Unal H (2004) Tribological studies of bronze filled PTFE polymer. Sci Eng Comp Mater 11(1):27–34

Unal H, Sen U, Mimaroglu A (2004) Dry sliding wear characteristics of some industrial polymers against steel counterface. Tribol Int 37(9):727–732

Yamamoto Y, Hashimoto M (2004) Friction and wear of water lubricated PEEK and PPS sliding contacts: Part 2. Composites with carbon or glass fibre. Wear 257(1–2):181–189

Yamamoto Y, Takashima T (2002) Friction and wear of water lubricated PEEK and PPS sliding contacts. Wear 253(7–8):820–826

Yoon ES, Singh RA, Kong H, Kim B, Kim DH, Jeong HE, Suh KY (2006) Tribological properties of bio-mimetic nano-patterned polymeric surfaces on silicon wafer. Tribol Lett 21(1):31–37

Zhang MQ, Rong MZ, Yu SL, Wetzel B, Friedrich K (2002) Effect of particle surface treatment on the tribological performance of epoxy based nanocomposites. Wear 253(9–10):1086–1093

Tribology in Polymers and Polymers Composites

Scientific Insights on Tribological Aspects of Polymer Based Composites

Dheeraj Kumar Gara, G. Raghavendra, Shakuntala Ojha, Sri Bandyopadhyay, Syed Ismail, and R. Narasimha Rao

Abstract Polymer composites are those materials that form a synergistic mechanical advantage when reinforcement fillers are integrated into polymer. This advantage of the multiphase material possesses excellent wear and friction properties, hence found to be amenable with aerospace, automobile, and biomedical applications. The current article emphasizes the Tribological properties of various polymer composites concisely. However, alongside the Tribological advantage, there is a compromise in mechanical properties due to exposure of polymer composites to hazardous environments resulting in degradation and plasticization. With the advent of new manufacturing and processing techniques, by retaining the mechanical properties, the Tribological properties can be enhanced. In the current article, detailed attention to the microscopic and macroscopic Tribological aspects of polymer composites will be emphasized.

Keywords Tribology · Polymer composites · Characterization · Crystallography · Wear · Friction

1 Introduction

Realizing the friction (Gnecco and Meyer 2015; Mo et al. 2009) and wear (Bhushan et al. 1995; Gotsmann and Lantz 2008) at nanoscale provides interesting insights into the physical behavior of the material. Materials possess good wear resistance at a macro scale such as diamond can be used as a coating, but the same diamond-like

D. K. Gara · G. Raghavendra (✉) · S. Ismail · R. N. Rao
Department of Mechanical Engineering, National Institute of Technology Warangal, Warangal, Telangana 506004, India
e-mail: raghavendra.gujjala@nitw.ac.in

S. Ojha
Department of Mechanical Engineering, Kakatiya Institute of Technology and Science, Warangal, Telangana, India

S. Bandyopadhyay
School of Materials Science & Engineering, UNSW. Sydney, Kensington, NSW 2052, Australia

H. Jena et al. (eds.), *Tribology of Polymer and Polymer Composites for Industry 4.0*, Composites Science and Technology, https://doi.org/10.1007/978-981-16-3903-6_2