Journal of Scientific & Industrial Research
Vol. 81, July 2022, pp. 730-739

Mechanical and Tribological Performance of Polypropylene/Tin Powder Composites

Mustafa Gulesen[1]*, Salih Hakan Yetgin[2] & Hüseyin Unal[3]

[1]Kütahya Dumlupinar University, Faculty of Engineering, Evliya Çelebi Kampusu, Kütahya, Türkiye
[2]Tarsus University, Faculty of Engineering, Tarsus, Mersin, Türkiye
[3]Sakarya University of Applied Sciences, Faculty of Technology, Esentepe kampusu, Sakarya, Türkiye

Received 06 February 2021; revised 20 May 2022; accepted 17 June 2022

In this study, the effect of Tin powder filler content on the mechanical and tribological performance of Tin filled Polypropylene (PP) composites were investigated. Polypropylene composites were prepared in a Brabender kneading chamber. The melt was transferred to a laboratory hot press and compression molded into samples for tests. The mechanical performances of the polymer based composites were determined by tensile and notched izod impact tests. The tribological tests were carried out in dry condition using pin-on-disc at 0.5−1.5 m/s Sliding Speed (SS) and 10–30 N loads. The mechanical test results demonstrated that the incorporation of Tin powders increased the Tensile Strength (TS) (5.6%), tensile modulus (TM) (19.8%) and izod Impact Strength (IS) (41.8%) while decreased the Elongation at Break (EB) (80%) values of Tin powder filled PP composites. The Friction Coefficient (COF) and Specific Wear Rate (SWR) decreased with the increase in filler content. The COF of unfilled PP, PP-8% Tin powder, PP-16% Tin powder and PP-24% Tin powder composites decreased about 20%, 23.4%, 21.8% and 29.3% with the increase in applied load from 10 N to 30 N. The SWR of the Tin powder filled PP composites decreased by 91% compared to unfilled PP polymer at 1.5 m/s speed and 30 N load value.

Keywords: Coefficient of friction, Mechanical properties, Notched izod impact, Tensil, Tribology

Introduction

Some solid fillers such as Poly-Tetra-Fluoro-Ethylene (PTFE), graphite, solid wax, carbon black, molybdenum disulphide and many metallic powders such as copper oxide (CuO), aluminium oxide (Al_2O_3), zirconia (ZrO_2), titanium dioxide (TiO_2), zinc oxide (ZnO), zinc floride ($ZnFl_2$), silver (Ag), nickel (Ni) and iron (Fe) powder have been widely used for tribological applications in the electric/electronic industry, machine industry, food industry, and transportation industry. Some researcher investigated the effect of some solid lubricants on the tribological and mechanical performance of some thermoplastic and thermoset based polymer materials.[1,2]

Shamsuddin *et al.* studied the tribological and mechanical performances of Carbon Fiber (CF) reinforced and PTFE filled polycarbonate (CF-PC-PTFE) composites prepared with single screw extrusion machine and injection molding machine. The results exhibited that flexural and tensile strength increased with the increment of CF reinforcement, while with addition of PTFE it decreased. Also, COF and SWR of CF-PC-PTFE composites decreased with the addition of CF and PTFE into PC.[3]

Japic *et al.* studied tribological and mechanical performances of Glass Fiber (GF) reinforced and Expanded Graphite (EG) with various particle sizes (5 µm and 1000 µm) filled Polyamide 6 (PA6) composites. They observed that EG acts as a nucleating agent and inhibits the rate of crystallization at higher concentrations. In addition, from the dynamic mechanical analysis results, it was defined that the storage modulus rised with the addition of both EG types. As a result of tribological experiments, the lowest COF was obtained in 10 wt.% EG5 added composite. Furthermore, it was identified that the wear increased with the loading of both types of EG. In the literature some studies have been found showing the effect of filler type, filler size and ratio on the mechanical, thermal, tribological and electrical properties.[4]

Tavman investigated both thermal and mechanical performances of aluminium particle filled High−Density−Polyethylene (HDPE). They

*Author for Correspondence
E-mail: mustafa.gulesen@dpu.edu.tr

concluded that tensile stress and ultimate elongation values decrease with the increment of aluminium powder filler in the HDPE polymer.[5] Bishay *et al.* examined the electrical, mechanical and thermal performances of aluminium powder filled Poly-Vinyl-Chloride (PVC) composites. They realised that mechanical performances of aluminium powder filled PVC composite decreased with the increase in aluminium powder filler in PVC polymer matrix.[6] Maiti and Mahapatro investigated the effect of nickel powder on the mechanical behaviors of isotactic PP. They concluded that TS, TM and ultimate elongation decreased while bending strength (BS) and bending modulus (BM) rised with zinc powder content in PP polymer matrix.[7]

Rusu *et al.* studied the effect of various amount of zinc powder on the mechanical and thermal properties of HDPE. They concluded that maximum TS and TM are obtained for 4% zinc powder (by volume) filled and 14% zinc powder (by volume) filled HDPE composites, respectively.[8] Divya and Suresha investigated the mechanical and tribological performance of 60 wt.% CF filled epoxy (CF-Ep) nanocomposites filled with different amount (0.5 and 1.0) of aluminum (Al) and zinc (Zn) metallic nanoparticles. The 0.5 wt.% Zn and Al nanoparticle filled CF-Ep composites showed higher tensile properties. Moreover, flexural strength (FS) and flexural modulus (FM) of CF-Ep composite also increased with the increase in filler ratio. As a result of tribological experiments, the superior WR was obtained in 0.5 wt.% Zn nanoparticle filled CF-Ep composite.[9]

Gungor *et al.* investigated the mechanical performance of various amount (5–15 wt.%) of iron powder filled HDPE polymer composites. They observed that yield strength, TS, EB and IS values decrease while TM and hardness values increased with the increment of iron powder filler in the HDPE.[10] Kursuncu *et al.* studied the mechanical and tribological performances of PP composites filled with iron scales of different size. As a result of study, it was stated the WR and TS of PP polymer composite material in all grain sizes were increased with the loading of iron scale. Besides, the COF was decreased with the increment of load.[11] Ghosh and Maiti studied the mechanical behaviour of isotactic PP composites filled with silver powder filler. They concluded that TM, TS, impact strength and ultimate EB values reduce with the loading of silver powder filler content to the isotactic PP polymer.[12]

Many researchers also reported the effect of metallic and nonmetallic powder fillers on the tribological and mechanical performances of materials.[13–16] Bahadur *et al.* investigated the effect of composition, transfer film layer and bonding on the friction and wear performance of Poly−Phenylene Sulphide (PPS) composites filled with nano particles of CuO, ZnO and TiO_2. They concluded that SWR values of PPS composite filled with CuO and TiO_2 powder decreased while it increased with ZnO powder addition into the PPS polymer matrix.[13] Kutelia *et al.* investigated the physical, mechanical and tribological properties of metallic and nonmetallic nanoparticles filled PTFE composites. Boron nitride (BN), boron carbide (B_4C) and Co were used as nano-powder fillers in small amounts (5−10 wt.%).[14]

Guglani and Gupta prepared Nylon 66 based micro-composites filled with various amount of titanium dioxide (TiO_2) filler using an extruder and investigated the mechanical and tribological performances. They found that the TiO_2 added up to 6 wt.% to nylon 66 polymer caused an increase in TM, TS, FM, FS, impact and compression strength values of the composite. They found that the mechanical values of the composite reduced as a result of the addition of more than 6wt.%TiO_2. In addition, up to 6 wt.% TiO_2, TS-TM, FS-FM, impact, and compression strength all increased, but thereafter decreased at greater filler loading ratios. It was discovered that a micro-TiO_2-Nylon 66 composite with a TiO_2 filler ratio of 6 wt.% decreased wear and COF. The COF and WR increased with the increment of applied load and speed values.[15] Latha and Rao investigated the mechanical and wear behaviors of TiO_2 and ZrO_2 filled bamboo-glass-epoxy hybrid composites. Filler material weight percentages in the hybrid composite were varied between 3, 6, and 9%. In comparison to the TiO_2 filler composite, ZrO_2 filler provides superior strength and wear resistance.[16]

Some researchers studied metal powder filled polymer composites.[17–20] Brostow *et al.* analysed the effect of metal particles such as aluminium, silver and nickel with micrometer diameters on the mechanical, tribological and microstructural performances of low density polyethylene and thermoplastic elastomer materials. They realised that higher tensile modulus and hardness values are obtained with higher amount of metal powder addition into the LDPE polymer.[17] Keshavanarayana *et al.* reported that the tribological performance of metal fillers such as copper, alumium and steel and ceramic filler such as alumina filled polystyrene composites. They realised that the best wear resistance values were found for aluminium-ceramic-polystyrene hybrid composite.[18]

Burya *et al.* studied the effect of various metallic filling materials on the mechanical, physical and WR of aromatic polyamide based polymer composite. They concluded that wear resistance increases with the increase in metal powder filler in the polyamide-based composites.[19] Krishna *et al.* examined the wear and friction performances of polystyrene reinforced with steel powder, alumina powder and a combination of steel and alumina powders. They found that among the materials studied ceramic-polymer composite has the lowest WR.[20] Some researchers also studied nano size metal powder filled polymer composites.[21–24] The characteristics of polymer-based brake composites with varying quantities of copper (0, 5, 10, and 15 wt.%) and rare earth lanthanum oxide (0, 5, 10, and 15 wt.%) powder additions were examined by Zheng *et al.*[21] They found that lanthanum oxide can be used efficiently instead of copper in brake composites. When compared to adding copper powder to brake composites, lanthanum oxide is more conductive to the creation of compacted friction films, which improves the brake composites' tribological capabilities.[21] Wang *et al.* investigated the mechanical and wear properties of nylon 1010 (PA1010) filled with zinc oxides (ZnO) particles and ZnO whiskers under dry sliding condition. The mechanical and wear behaviours of PA1010 composites are improved by ZnO particles and ZnO whiskers, according to experimental the results. The addition of ZnO particles and ZnO whiskers to composites increases their hardness, tensile strength and scratch coefficient. When the filler quantity is less than 10 wt.%, particle-filled composites have lower wear rates than whisker-filled composites.[22]

Palanikumar *et al.* studied the tribological performance of $CaCO_3$ filled PP composites with various loads and SS. It was stated that the weight loss decreased with increasing $CaCO_3$ amount while increased with the increase of applied load and SS.[23] Danilova *et al.* studied the thermodynamic, mechanical, and tribological properties and structure of Ultra-High-Molecular Weight Polyethylene (UHMWPE) with additions of 0.5–20 wt.% synthetic $CaSiO_3$ wollastonite. Wollastonite was discovered to be involved in the friction and wear processes of UHMWPE composites.[24] Bahadur *et al.* investigated the tribological behaviour of PA11 polymers with ZnF_2, ZnS, and PbS fillers. They also concluded that sulphides, fluorides, and oxides of zinc fillers increased the WR of PA11 polymer composites.[25]

There are a few studies on the mechanical behaviour of polymer composites containing Tin powder filler in the literature. Aluminium, zinc, tin, iron and copper powders were employed by Glogowska *et al.*, with concentrations ranging from 2.5 to 15 wt.% relative to a PP composite. The correlations between different metal powder filler content and TM, maximum TS, tensile stress at break, Shore D hardness and Charpy impact strength were determined.[26] They concluded that tensile stress at break values increased up to 7.5% tin content, it remained stable in Tin content more than this rate. In addition, while TM and shore D hardness values increased slightly up to 5% Tin filler content, they remained stable over that value. The rate of increase in TM and Shore D hardness are around to be 12.5% and 3.2%, respectively. TS values increased up to 5% Tin filler content, above this ratio, it decreased. The rate of increase in TS is around 3%. Copper-Tin (Cu-Sn) alloys are named as bronze materials. Bronze materials are used in shaft-bearing applications in many areas of industry. The Tin metal in the Tin bronze shows high mechanical and wear resistance properties.[26]

This study investigated the mechanical and wear resistance property of Tin in polymer materials. In addition, the usability of Tin powder filler added PP polymer composites in shaft bearing applications was investigated. So, mechanical and tribological tests were carried out. Tensile strength, tensile modulus, elongation at break and impact strength were measured and analysed mechanically. Tribological behaviours such as COF and SWR of the Tin powder filled polymer composites were recorded and evaluated.

Materials and Methods

Materials

The polypropylene polymer used in this study is an industrial product (Akulon F 223 D), Turkey. Tin powder particles were produced using gas atomization unit. The manufacturing of Tin powder filled polypropylene composites is given schematically in Fig. 1. In the first process, Delaval type nozzle system and nitrogen gas were used, see detail of gas atomization unit in Fig. 2. During atomization process, Tin powder was heated above 400℃ melting temperature at 15 bar atomization gas pressure. The Tin powder size is measured using Malvern

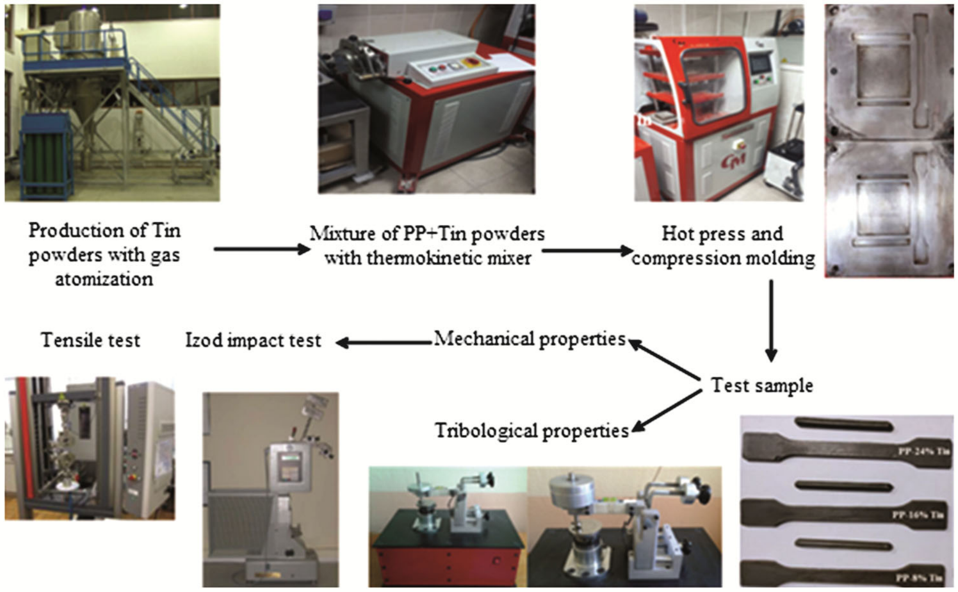

Fig. 1 — Manufacturing process of Tin powder filled Polypropylene composites

Fig. 2 — Detail of gas atomization unit

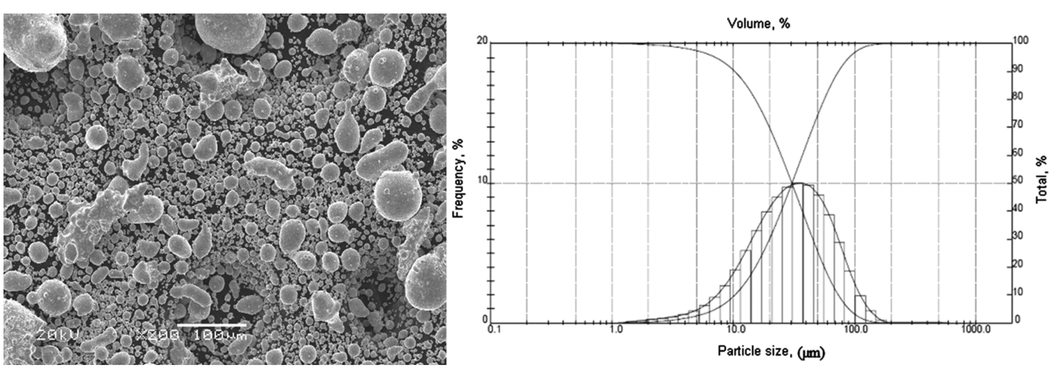

Fig. 3 — SEM pictures of Tin powder and powder size distribution produced under 15 bar gas pressure

Mastersizer brand E lazer particle size measurement machine. Scanning Electron Microscope (SEM) pictures of Tin powders and powder size distribution produced under 15 bar gas pressure are given in Fig. 3 (a) and (b), respectively. Tin powder particle size is a round (d_{50}) 25 µm, see Fig. 3 (b).

Sample preparation and experimental tests

In this study, composite samples were produced through three stages. Firstly, polypropylene-Tin powder with weight content ratio 92/8, 84/16, 76/24 composites were prepared in a thermokinetic mixer. The components with certain prescription were kneaded for four minutes in a chamber, and then

Table 1 — Mechanical properties of materials investigated in the study

Materials	Tensile modulus, MPa	Tensile strength, MPa	Elongation at break, %	Izod impact strength, kj/m^2	Density, g/cm^3	Shore-D
PP	510 ± 23	22.9 ± 2.0	210 ± 0.33	16.0 ± 1	0.90	72 ± 0.4
PP-8% Tin powder	591 ± 30	23.5 ± 1.1	170 ± 0.46	19.2 ± 1	0.96	73 ± 0.6
PP-16% Tin powder	598 ± 19	24.0 ± 1.8	90 ± 0.28	20.1 ± 1	1.04	74 ± 0.3
PP-24% Tin powder	611 ± 21	24.2 ± 2.2	42 ± 0.15	22.7 ± 1	1.14	74 ± 0.4

preheated to 190°C, with a rotor speed of 50 rev/minute. Finally, the melt was transferred to a laboratory hot press and compression molded into test samples (see Fig. 1). The pressing temperature were 215°C at 30 bar pressure for 1.5 minutes, 60 bar for 1.5 minutes and 100 bar for 2 minutes, respectively. Tensile tests were performed on a Zwick Z020 universal tensile test machine utilizing a dumbbell-shaped specimen under the ASTM D638 standard at a crosshead velocity of 20 mm per minute. According to ASTM D256 standard, a notched izod impact test was performed using a Zwick brand pendulum impact tester, and impact strength data values were recorded. V type notch specimen sized 4 × 10 × 40 mm^3 were prepared. Impact testing on notched izod were carried out at room temperature (23°C ± 2) with a 15 J hammer. At least five test samples were tested for each condition, with average values provided. The pin-on-disc wear test machine that was constructed and used for this study is also shown in Fig. 1. Wear tests were performed under applied load values of 10 N, 20 N and 30 N and SS of 0.5, 1.0 and 1.5 m/s against stainless steel (AISI 440C) disc at room temperature (23°C ± 2 and 53 ± 2% humidity) under dry sliding conditions. Wear tests were conducted on samples having a diameter of 6 mm and a length of 50 mm. A load cell is used to measure friction force during the wear test. From tribological test, COF and SWR values were calculated and evaluated. The amount of wear was determined by weighing the pin in a precision balance before and after the testing with an accuracy of 1×10^{-4} g. The samples were ultrasonically cleaned and dried in warm air before and after each test. To compute SWR (K_o), Eq. (1) was used where, Δ_m represents average weight loss (g), L: represents distance (m), F represents the load (N) and ρ represents density (g/cm^3). Each test was conducted three times, with a closest results being taken into account and the average values being displayed.

$$K_o = \frac{\Delta_m}{L * F * \rho} \qquad \ldots (1)$$

Results and Discussion

The mechanical and physical parameters of PP−Tin powder polymer composites is shown in Table 1. Shore-D hardness, TM, TS and IS values all increased as the Tin powder filler concentration increased, while EB values fell. The increase in TM for PP-8%Tin powder, PP-16% Tin powder and PP-24% Tin powder filled composites are 15.8%, 17.2% and 19.8%, compared with the unfilled PP polymer, respectively. This is explained by the theory of percolation by He and Jiang.[27] The stress concentration has an effect on the polymer zone around each particle, according to this theory. As a result, if the distance between the particles is too tiny, these regions collide and create the percolation network, which increases the tensile module. The TS values are also increased with the increment of Tin powder filler content. Compared with the unfilled PP polymer, the TS of PP-8% Tin powder, PP-16% Tin powder and PP-24% Tin powder composites increased by 2.6%, 4.8% and 5.6%, respectively. When compared with the unfilled PP polymer, there was 20% increase in the IS with as little as 8% Tin powder. With the addition of 16% Tin powder, the IS increased from 16 to 20.1 kJ/m^2, and with 24% Tin powder it increased further to 22.7 kJ/m^2 which is a 41.8% increase.

A similar result was obtained by Divya and Suresha.[9] Divya and Suresha stated that the impact energy increased with the increase of metallic nanoparticles.[9] However, EB values reduced with increasing Tin powder filler from 8 to 24 wt.%. The EB of 8 wt.%, 16 wt.% and 24 wt.% Tin powder filled PP composites decreased by 19%, 57.1% and 80% compared to the unfilled PP polymer, respectively. The reason of the increase in mechanical properties could be because of restriction in the chain mobility and decreased deformation ability of the matrix with the addition of filler. The limitation on the mobility of polymer chains decreases the stress transfer from the whole composite which in turn causes increase in rigidity and stiffness and decrease in elongation at break.[28] The Shore-D hardness values of unfilled PP and Tin powder filled PP composites is also shows in Table 1. Accordingly, the hardness values vary between 72 and 74 Shore-D. It was observed that the hardness values of Tin powder filled PP composites increased with the addition of Tin powder. This increased hardness is owing to the dispersed-phase particles' high stiffness and hardness, which allows for strengthening due to their load-carrying capacity[9] and macromolecule orientation.[24]

The SEM pictures presented in Fig. 4 show the fracture surfaces of PP-16% Tin powder and PP-24% Tin powder composites. It can be been seen in Fig. 4 (a) and (c) that the Tin powder uniformly distributed in PP matrix. Also, it can be seen in Fig. 4 (b) and (d) that the Tin powders are pull-out of the PP polymer. This is due to the decreased bonding strength of the interface between Tin powders and PP matrix. The tensile strength and modulus of Tin powder filled PP composites has not increased enough because of the weaker interfacial bonding strength. Energy Dispersive Spectrometry (EDS) analysis of the SEM picture is given in Fig. 4 (f) for PP-24% Tin powder composites illustrating in Fig. 4 (e). Energy Dispersive Spectrometry analysis (Fig. 4f) of PP-24% Tin powder composites detected the presence of elements of Tin, C and O.

The COF versus sliding distance of 1000 m for unfilled PP polymer and Tin powder filled polypropylene composites under applied load value of 20 N at 1.0 m/s SS are given in Fig. 5. As seen in Fig. 5, the COF value of PP shows large scale behavior while Tin powder filled PP composites show little scale behaviors. The COF of unfilled PP polymer and Tin powder filled PP composites changed in two stages as initial and steady-state circumstances, as shown in Fig. 5. The COF grew substantially in the first stage. After about 200 m of sliding distance, the COF of the unfilled PP polymer and Tin powder filled PP composites reached a stable value in the second stage, known as steady-state. The COF for the

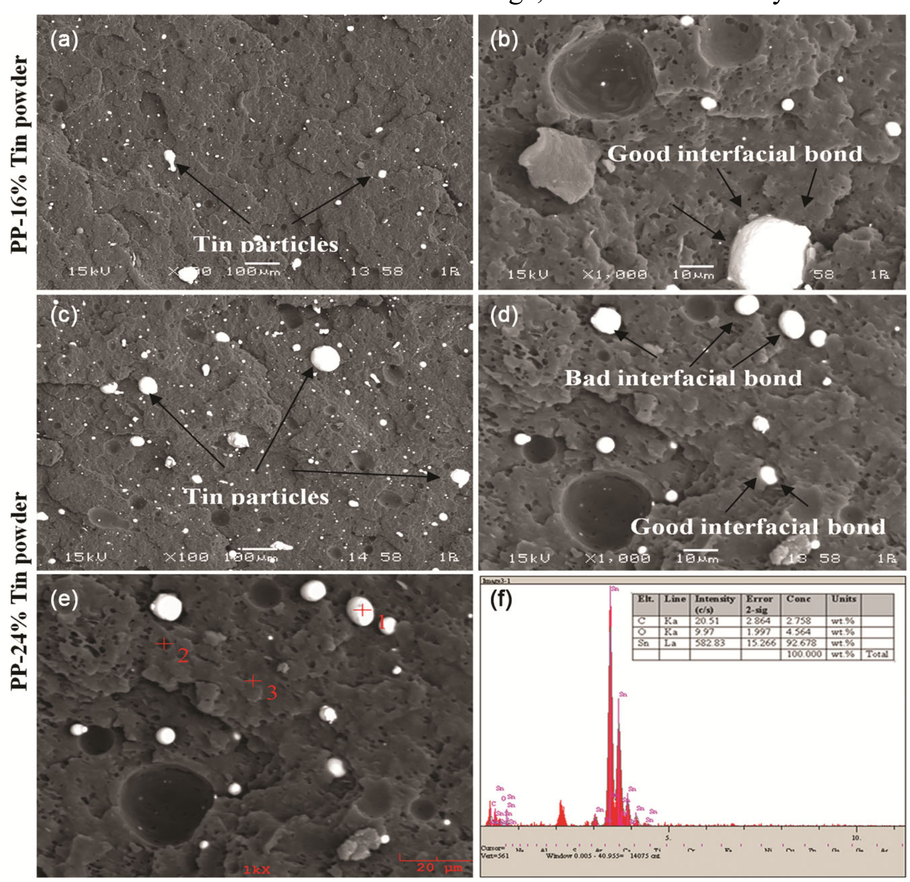

Fig. 4 — Tensile cross-sectional SEM pictures of PP-16% Tin powder and PP-24% Tin powder composites

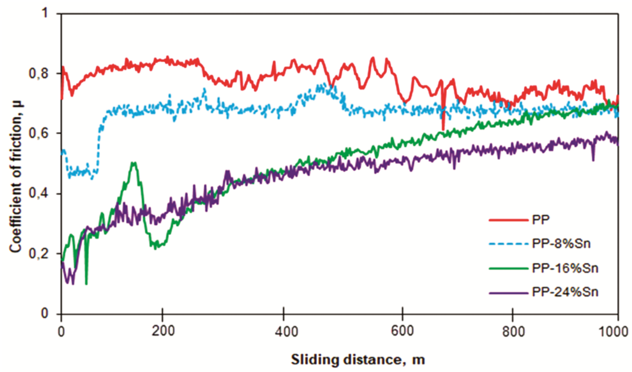

Fig. 5 — The relationship between COF and sliding distance for unfilled PP polymer and PP-Tin powder composites (applied load: 20 N, SS: 1.0 m/s)

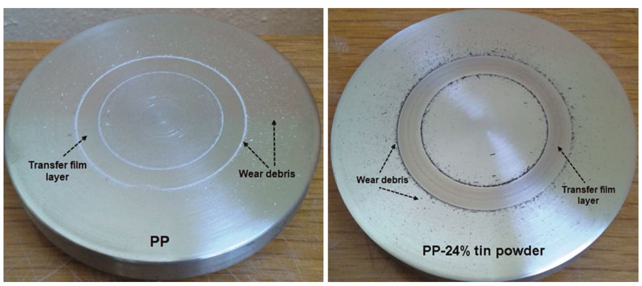

Fig. 6 — Macro-pictures disc surface of PP and PP-24% Tin powder composites

unfilled PP polymer is between 0.7 and 0.8, while the COF of Tin powder filled PP composites is decreased to the value of 0.2–0.6. Latha and Rao stated that the matrix type and, shape, size and content of the particles significantly affect the friction and wear properties of the polymers.[16] It has been stated that the submicron particles added to the polymer matrix affect the tribological properties by forming a transfer film layer on the counter disc.[16,24] Geometric factors, deformation, and creation of the transfer film layer were also blamed by Samyn and Schoukens for the COF drop.[29] The COF of Tin filled PP composites dropped as a result of the introduction of the transfer film layer, which prevented direct contact between the disc material and polymer matrix. When the disc pictures in Fig. 6 were analyzed, a transfer film layer and wear debris were discovered, reducing the friction between the PP-24% Tin powder composites pin and the steel disc.

The relationship between COF and Tin powder filler contents at various speeds and loads values for unfilled PP polymer and PP-Tin powder filled composites are given in Fig. 7. The COF values of unfilled PP polymer at the load of 10 N, 20 N and 30 N and under 0.5 m/s SS

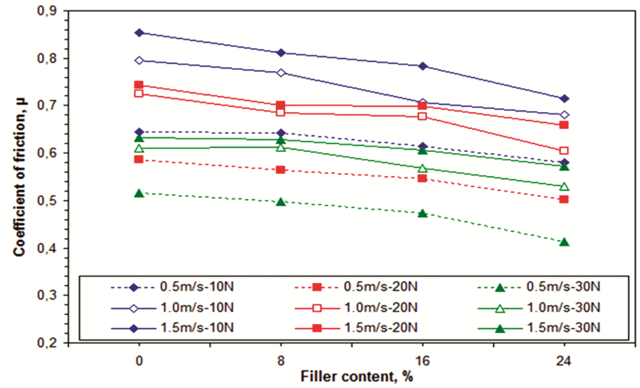

Fig. 7 — The relationship between COF and Tin powder contents at different speeds and loads for unfilled PP polymer and PP-Tin powder composites

are 0.64, 0.58 and 0.51, respectively. Under 1.5 m/s SS are 0.85, 0.74 and 0.63, respectively. The COF values of unfilled PP under 10 N load and at 0.5, 1.0 and 1.5 m/s SS are 0.64, 0.79 and 0.85, respectively. Moreover, the COF for unfilled PP polymer under the load of 30 N and at 0.5 m/s, 1.0 m/s and 1.5 m/s SS are 0.51, 0.61 and 0.63, respectively. The COF of PP-8% Tin powder filled composite under 10 N load and 0.5, 1.0 and 1.5 m/s SS are 0.64, 0.77 and 0.81, respectively. In addition, the COF of PP-16% Tin powder filled composite under 10 N load and at 0.5, 1.0 and 1.5 m/s SS are 0.61, 0.70 and 0.78, respectively. Furthermore, the COF values of PP-24% Tin powder filled composite under the 10 N load and 0.5, 1.0 and 1.5 m/s SS of are 0.58, 0.68 and 0.71, respectively. The COF rose as the SS increased for all materials. The increasing ratios in COF values for PP polymer, PP-8% Tin powder, PP-16% Tin powder and PP-24% Tin powder composites are 32.8%, 26.5%, 27.8%, and 22.4%, respectively. As the SS rises, the frictional asperities interacting with the contacting surface create a high temperature. The faster the SS, the higher the temperature rise at the materials' contact surface. The sticky component increases as the temperature approaches the polymer's softening point, resulting in high COF values.[30,31] In addition, the COF of unfilled PP, PP-8% Tin powder, PP-16% Tin powder and PP-24% Tin powder composites decreased 20%, 23.4%, 21.8% and 29.3% with the increasing of load from 10 N to 30 N, respectively. As seen in Fig. **7**, the COF reduced as the Tin powder filler concentration increased. At 1.5 m/s SS and 20 N load, the COF of PP-8%Tin powder, PP-16% Tin powder and PP-24% Tin powder composites decreased by 5.7%, 7.2% and 12.1% compared to unfilled PP polymer. Metal fillers usually enhance the abrasive force and lower the true contact area during friction operations.[32] Tin powder's selflubricating effect is another major reason for COF reduction (see Fig. 6). As a result, COF has been on the decline, with filler content increasing in the majority of cases.

The process parameters such as load, speed, sliding distance, temperature, and time influence the tribological performance of the thermoplastic polymer composites, such as strong wear resistance and low COF.[33] The relationship between COF and TM for unfilled PP polymer and Tin powder filled PP composites are given in Fig. 8. The COF values decrease with the increase in TM for PP polymer and Tin powder filled PP composites. Kalacska stated that the relationship between COF and modulus of elasticity depends on surface roughness, metallic composition of mating surfaces, and other system properties (e.g., temperature). During steady-state friction, the pin-on-disc measurements primarily showed a linear relationship between the friction and modulus of elasticity.[34] Chand *et al.* stated that the wear resistance increased with increase in the mechanical and physical properties such as TS and hardness of polymers. They stated that the increased wear life is due to the rapid comminuting at the particle and matrix interface due to the increase in filler-filler contact.[35] However, Alajmi and Shalwan determined that there was no relationship between SWR and mechanical properties. Between the mechanical properties and COF, it was defined that the young modulus is a more effective parameter than the hardness. It was also discovered that increasing TS and EB lowers the COF.[36]

The connection between SWR and Tin powder filler content in unfilled PP polymer and PP-Tin powder composites is depicted Fig. 9. The addition of Tin particles to PP polymer reduces the SWR, as seen in Fig. 9. Under 1.5 m/s SS and 20 N load, compared with unfilled PP, the SWR of PP-8% Tin, PP-16% Tin and PP-24% Tin composites decreased by 23.8%, 44.4% and 116.6%, respectively. On the other hand, at 1.5 m/s SS and 30 N load, the SWR of the Tin powder filled PP composites decreased by 91% compared to unfilled PP polymer. Wear resistance was higher in high Tin amount than in low Tin amount due to more homogeny distribution of particles with high resistance to abrasion. The rigid particle can operate as a load carrier, distributing the applied stress through it, which is why the WR is reduced.[23] Furthermore, the lubricating effect of Tin powder and the higher mechanical strength of the PP composite may be responsible for the lower SWR. Li and Liang also found that the SWR is highly reliant on the pace at which transfer film forms on the materials' contact surfaces.[37] When the load was raised from 10 N to 30 N, The SWR dropped. This reduction was 23.5% for unfilled PP polymer, 38.4% for PP-8% Tin powder, 45.5% for PP-16% Tin powder and 56.2% for PP-24% Tin powder composite. The SWR of the unfilled PP polymer and Tin powder filled PP composites increased with increasing SS. SS increased the SWR by 192.1%, 153.0%, 168.6% and 150.0% for unfilled PP polymer, PP-8% Tin powder, PP-16% Tin powder and PP-24% Tin powder composites, respectively. The rise in SWR is due to the loosened material between contact surfaces increasing the value of COF. The temperature of the contact surface rises, reducing mechanical cohesiveness and causing the components to erode.[15] Particles are released from the matrix under high load and SS, generating an increase in the

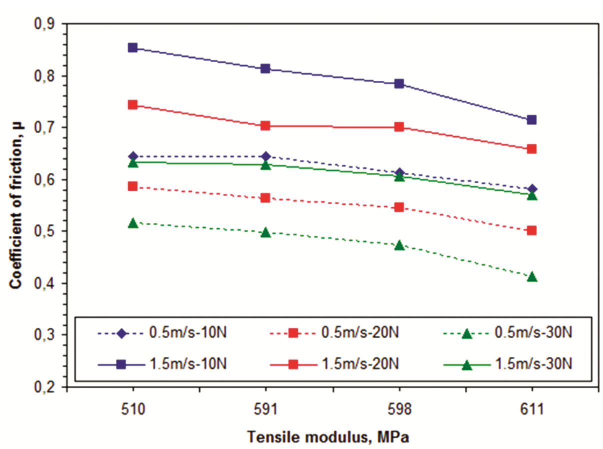

Fig. 8 — The relationship between COF and tensile modulus for unfilled PP polymer and PP-Tin powder composites

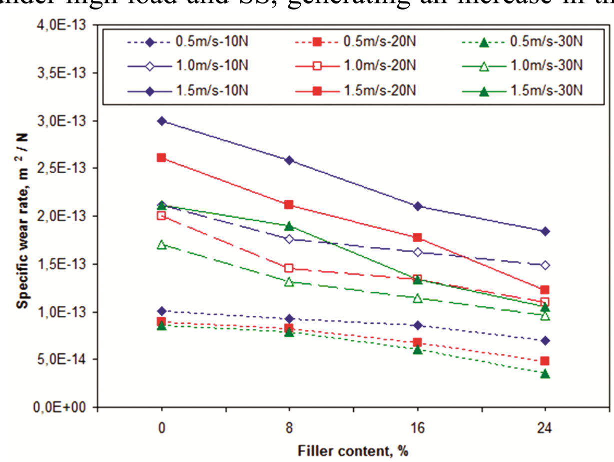

Fig. 9 — The relationship between SWR and Tin powder contents for unfilled PP polymer and PP-Tin powder composites

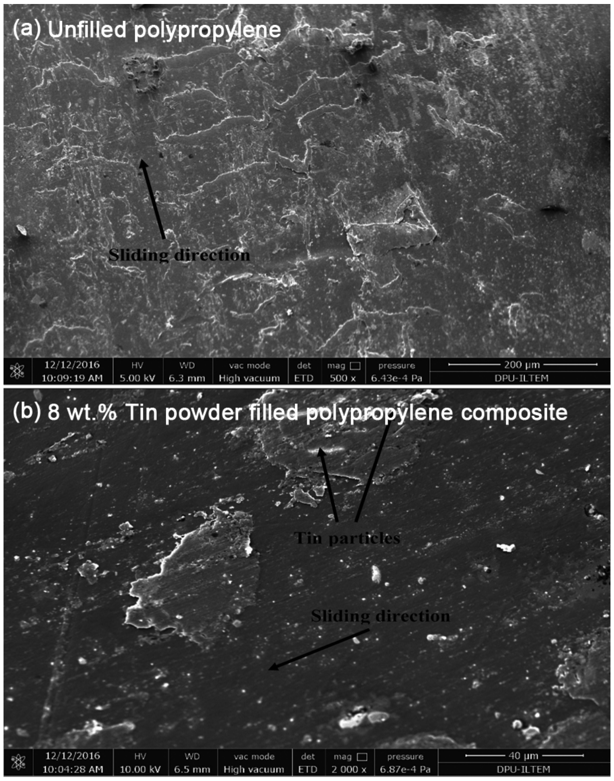

Fig. 10 — SEM micrographs of pure PP and 8% Tin filled PP composite pins worn surfaces: (a) Unfilled polypropylene, (b) 8 wt.% Tin powder filled polypropylene composite

degree of wear. Filler detachment and presence in the friction zone causes abrasion of the polymer material, which is then removed as wear particles while friction contact continues.[24] For the load and SS ranges investigated in this work, the SS had a greater impact on the SWR of unfilled PP polymer and Tin powder loaded PP composites. The highest SWR is for unfilled PP with a value of 3.0×10^{-13} m^2/N at 1.5 m/s SS and under 10 N load. The lowest SWR is about 3.5×10^{-14} m^2/N for PP-24% Tin powder composites under at 0.5 m/s SS and 30 N load.

The SEM micrographs of unfilled PP and 8% Tin filled PP composite pin worn surfaces are given Fig. 10. Sign of plastic deformation due to the softness of unfilled PP material is shown in Fig. 10 (a), while PP-8% Tin powder composite show smoother surface due to rubbing of hard Tin particles which lead to lower SWR performance is shown in Fig. 10 (b). In the figures, it is seen that Tin particles adhere to the polymer pin surface and form a thin film layer. This causes a decrease in the SWR. Furthermore, Fig.10 (b) also shows discretely homogenous distribution of Tin particles without any sign of agglomeration of these particles.

Conclusions

For the test operating range, with the addition of Tin powder to the polypropylene, SWR and COF of the composites decreased. The reduction rate in the COF was 5.6%, 6.5% and 16.1% respectively, depending on the 8, 16 and 24% Tin powder filler ratio in PP. The average reduction in SWR was about 30.6%, 48.5% and 97.6% for PP-8% Tin, PP-16% Tin and PP-24% Tin powder filler ratio, respectively. In addition, little increase in mechanical properties was detected. The highest SWR is for unfilled PP with a value of 3.0×10^{-13} m^2/N at 1.5 m/s SS and under 10 N load. The lowest SWR is 3.5×10^{-14} m^2/N for PP-24% Tin powder composites at 0.5 m/s SS and 30 N load value. The results obtained give an idea about the usability of Tin powder filled PP composites in shaft bearing applications.

References

1 Unal H & Yetgin S H, The investigation of tribological performance of polyamide 6 polymer and polyamide 6/wax blend against themselves, *J Fac Eng Archit Gazi Univ*, **31(2)** (2016) 457–463.

2 Schwartz C J & Bahadur S, Studies on the tribological behaviour and transfer film–counterface bond strength for polyphenylene sulfide filled with nanoscale alumina particles, *Wear*, **237** (2000) 261–273.

3 Shamsuddin M S M, Nasir R M, Aziz H & Mohd Ishak Z A, Mechanical and tribological properties of solid lubricant (PTFE) filled carbon fiber reinforced polycarbonate composites, *AIP Conf Proc*, **2267** (2020) 020031.

4 Japic D, Simon K, Mitjan K, Janez S, Blaz N & Miroslav H, Effect of expanded graphite on mechanical and tribological properties of polyamide 6/glass fibre composites, *Adv Polym Technol*, (2022) 9974889.

5 Tavman I H, Thermal and mechanical properties of aluminum powder filled high density polyethylene composites, *J Appl Polym Sci*, **62** (1996) 2161–2167.

6 Bishay I K, Abd-El-Messieh S L & Mansour S H, Electrical, mechanical and thermal properties of polyvinyl-chloride composites filled with aluminum powder, *Mater Des*, **32** (2011) 62–68.

7 Maiti S N & Mahapatro P K, Mechanical properties of nickel powder filled polypropylene composites, *Polym Compos*, **13(1)** (1992) 47–52.

8 Rusu M, Sofian N & Rusu D, Mechanical and thermal properties of nickel powder filled high density polyethylene composites, *Polym Test*, **20** (2001) 409–417.

9 Divya G S & Suresha B, Role of metallic nanofillers on mechanical and tribological behaviour of carbon fabric reinforced epoxy composites, *Mater Sci Appl*, **9** (2018) 740–750.

10 Gungor A, Mechanical properties of iron powder filled high density polyethylene composites, *Mater Des*, **28** (2007) 1027–1030.

11 Kursuncu B, Azmi E, Sabri G M & Bilal D, Investigation of mechanical and tribological properties of different grain size iron scale reinforced polymer composite, *Polym Polym Compos*, **29(9)** (2021) 1543–1550.

12 Ghosh K & Maiti S N, Mechanical properties of silver-powder filled polypropylene composites, *J Appl Polym Sci*, **60** (1996) 323–331.

13 Bahadur S & Sunkara C, Effect of transfer film structure, composition and bonding on the tribological behavior of polyphenylene sulfide filled with nano particles of TiO_2, ZnO, CuO and SiC, *Wear*, **258** (2005) 1411–1421.

14 Kutelia E, Gventsadze D, Padgurskas J, Gventsadze L & Tsurtsumia O, Investıgatıon of the trıbologıcal properties of polytetrafluorethylene modifıed wıth metallıic and nonmetallic nanoparticles, *The 8th Int Conf BALTTRIB'2015* (Aleksandras Stulginskis University) 26-27 November 2015.

15 Guglani L & Gupta T C, Study of mechanical and tribological properties of nylon 66-titanium dioxide microcomposite, *Polym Adv Technol*, 29 (2018) 906–913.

16 Latha P S & Rao M V, Investigation into effect of ceramic fillers on mechanical and tribological properties of bamboo-glass hybrid fiber reinforced polymer composites, *Silicon*, **10** (2018) 1543–1550.

17 Brostow W, Buchman A, Buchman E & Oscar O M, Microhybrids of metal powder incorporated in polymeric matrices: Friction, mechanical behavior, and microstructure, *Polym Eng Sci*, **48(10)** (2008) 1977–1981.

18 Keshavanarayana G, Divakar C, Venkatesh K, Mohan C B, Bhatta K G L & Murali L, Tribological studies on effect of mixture of fillers in polystyrene matrix composites, *J Thermoplast Compos Mater*, **27(9)** (2014) 1192–1208.

19 Burya A I & Yeriomina Y A, The effect of various metallic filling materials on the wear resistance of aromatic-polyamide-based composite materials, *J Frict Wear*, **37(2)** (2016) 151–154.

20 Krishna K G, Divakar C, Venkatesh K, Mohan C B & Mahesh L K S, Tribological studies of polymer based ceramic-metal composites processed at ambient temperature, *Wear*, **266(7-8)** (2009) 878–883.

21 Zheng K, Gao C, Fushan H & Youxi L, The role of rare earth lanthanum oxide in polymeric matrix brake composites to replace copper, *Polymers*, **10** (2018) 1027.

22 Wang S, Shirong G & Dekun Z, Comparison of tribological behavior of nylon composites filled with zinc oxide particles and whiskers, *Wear*, **266** (2009) 248–254.

23 Palanikumar K, AshokGandhi R, Raghunath B K & Jayaseelan V, Role of calcium carbonate ($CaCO_3$) in improving wear resistance of Polypropylene (PP) components used in automobiles, *Mater Today Proc*, **16** (2019) 1363–1371.

24 Danilova S N, Sofia B Y, Yuri N K, Ivan G Z, Igor Y B, Aitalina A O, Pavel S G & Evgeniy P S, UHMWPE/$CaSiO_3$ nanocomposite: Mechanical and tribological properties, *Polymers(Basel)*, **13(4)** (2021) 570.

25 Bahadur S & Kapoor A, The effect of ZnF_2, ZnS, PbS fillers on the tribological behavior of nylon 11, *Wear*, **155** (1992) 49–61.

26 Glogowska K, Janusz W S & Branislav D, Effect of mechanical properties of metal powderfilled hybrid moulded products, *J Polym Eng*, **36(7)** (2016) 705–712.

27 He D & Jiang B, The elastic modulus of filled polymer composites, *J Appl Polym Sci*, **49** (1993) 617–621.

28 Altay L, Mehmet S, Merve S, Tugce U & Yoldas S, The effect of various mineral fillers on thermal, mechanical, and rheological properties of polypropylene, *Res Eng Struct Mater*, **7(3)** (2021) 361–373.

29 Samyn P & Schoukens G, Thermochemical sliding interactions of short carbon fiber polyimide composites at high PV-conditions, *Mater Chem Phys*, **115(1)** (2009) 185–195.

30 Chen Z, Liu X, Lu R & Li T, Mechanical and tribological properties of PA66/PPS blend-III, reinforced with GF, *J Appl Polym Sci*, **102** (2006) 523–529.

31 Song H, Na L, Yanjie L, Chunying M & Zhen W, Preparation and tribological properties of graphene/poly (ether ether ketone) nanocomposites, *J Mater Sci*, **47** (2012) 6436–6443.

32 Kolesnikov I V, Metal–polymer tribosystems: basic recommendations for creating composites, *J Frict Wear*, **37(5)** (2016) 507–511.

33 Ravi P S & Mukesh K, Mechanical and tribological performance of polymer composite materials: A review, *J Phy Conf Ser*, **1455** (2020) 12033.

34 Kalacska G, An engineering approach to dry friction behaviour of numerous engineering plastics with respect to the mechanical properties, *Express Polym Lett*, **7(2)** (2013), 199–210.

35 Chand N, Prabhat S & Fahim M, Correlation of mechanical and tribological properties of organosilane modified cenosphere filled high density polyethylene, *Mater Sci Eng A*, **527(21-22)** (2010) 5873–5878.

36 Alajmi M & Shalwan A, Correlation between mechanical properties with specific wear rate and the coefficient of friction of Graphite/Epoxy composites, *Materials*, **8** (2015) 4162–4175.

37 Li J & Liang Z N, Sliding wear performance of TiO_2/short carbon fiber/Polyamide 66 hybrid composites, *Polym Plast Technol Eng*, **49** (2010) 848–852