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Tribological properties of compatabilizer and graphene oxide-filled polypropylene nanocomposites

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Abstract. Effect of maleic-anhydride-grafted-polypropylene (PP-g-MA) and graphene oxide (GO) addition on the tribological properties of polypropylene (PP) nanocomposites were investigated in this study. Graphene oxides with different levels (0.05 and 0.15 wt%) were used as reinforcing filler for PP nanocomposites. Maleic-anhydride-grafted-polypropylene (3 wt%) was added as a compatibilizer agent to increase the interaction between the GO and PP matrix. GO-filled PP nanocomposites with and without PP-g-MA were produced by a twin-screw extruder followed by injection moulding. Wear tests were carried out under dry sliding conditions against AISI 1040 steel disc using a pin-on-disc device at 0.4–1.6 m s^{-1} sliding speed and 10–40 N loads. The tribological test results showed that the coefficient of friction and wear rate of PP nanocomposites increased with applied loads and sliding speeds. The coefficient of friction decreased by 8.2, 14.2, 37.3 and 74.7% under 1.2 m s^{-1} sliding speed and 40 N load with the addition of PP-g-MA and GO to the PP nanocomposites. The wear rate of PP and its nanocomposites was 10^{-13} m^2 N^{-1}. The minimum wear rate was obtained for 0.15 wt% GO and 3 wt% PP-g-MA-filled PP nanocomposites with a value of 5.7537E^{-14} m^2 N^{-1} at 0.4m s^{-1} sliding speed and 10 N load in this study.

Keywords. Friction; wear; PP nanocomposites; graphene oxide; PP-g-MA.

1. Introduction

The most important advantages of polymeric materials are their low density and high strength/weight ratio. However, their usage areas are restricted because of their low mechanical properties, low thermal and electrical properties and high coefficient of friction under dry sliding conditions. Different types of fibres are added to polymer materials to improve its mechanical, tribological and other properties. Traditionally, micro-size fillers (glass, carbon aramid fibre, etc.) have been used to develop mechanical and tribological properties of polymer matrix. In recent years, carbon-based nanoparticles (carbon nanotube (CNT) and graphene oxide (GO)) have become the most important material group for improving the tribological properties of polymers because of their superior thermal, electrical, mechanical properties and high aspect ratios [1–5]. Amongst these fillers, GO is promising material owing to its remarkable mechanical properties and low-cost compared with CNT [6,7]. GO is compatible with most of the organic polymers due to a large number of oxygen-containing functional groups, such as, hydroxyl, carbonyl, carboxyl and epoxy [8–11].

GO-based materials (GOBMs), which are considered as derivatives of self-lubricating graphite, which have a layered structure and exhibit low friction and wear rate, are widely used in micro-/nano-electromechanical systems (MEMS/NEMS), functional additives, composites and bearing materials [9,12,13]. Liang *et al* [14] reported that GO films are suited as solid lubricants for MEMS/NEMS. The results of tribological tests showed that the coefficient of friction of the GO-coated silicon wafer was reduced to 1/6 of its value, and the wear volume is reduced to its 1/24, due to the GO films being soft compared to the silicon wafer. Thangavel *et al* [15] indicated that poly(vinylidene fluoride)–functionalized GO (PVDF–FGO) nanocomposite thin films show a high resistance to wear and can be potentially used in microelectronic devices. Shen *et al* [16,17] stated that GO can be used in epoxy composites as anti-wear material in brake applications, where constant and/or high friction is required. GOBMs have already been investigated in artificial joint implants. Tai *et al* [18] examined the mechanical and tribological properties of GO-filled ultra-high molecular weight polyethylene (UHMWPE) polymer composite. Tribological test results show that the wear rate of UHMWPE is significantly reduced when GO nanosheets are added up to 1 wt%. The addition of a small amount of GO could obviously increase the microhardness of UHMWPE and the GO/UHMWPE composite. Golchin *et al* [1] also investigated the tribological properties of multi-walled CNTs (MWCNTs) and GO reinforcement added into the UHMWPE polymer. As a result of this study, they reported that the friction coefficient and wear rate values reduced with the addition of the MWCNT and GO into UHMWPE polymer. An *et al* [19] investigated the friction and wear properties of UHMWPE polymer with GO reinforcement content. They also analysed the results obtained with ANOVA. As a result of this study, it was stated that the coefficient of friction increased slightly and the wear rate decreased with the addition of GO reinforcement into the UHMWPE polymer. Dong and Qi [20] stated that graphene-based materials can have great potential in bio-tribological applications with the resulting good biocompatibility and attractive bioactivity properties. Liu *et al* [21] studied the tribological properties of thermosetting polyimide/GO nanocomposites. They pointed out that the addition of GO clearly improved friction and wear properties of PI. The reason for this was stated as the formation of the transfer film layer and the increase in the load-carrying capacity. Song *et al* [2] examined the effect of load and sliding speed on tribological properties of poly-ether-ether-ketone (PEEK) composites with MWCNT, GO nanosheet and c-aminopropyl trimethoxysilane-modified GO (GO-Si) nanosheets. As a result of this study, it was stated that the coefficient of friction and wear rate decreased until 2.94 N applied load and then, increased after this load value. In addition, the friction coefficient and wear rate increased at the sliding speed of $0.0628\,\mathrm{m\,s^{-1}}$ and higher. Yuanshi *et al* [22] have investigated the mechanical and tribological properties of GO and nano-$\mathrm{MoS_2}$-filled polyimide (PI) polymer composites. As a result of the tribological tests carried out under 6 N load, friction coefficient and wear rate decreased, when the GO added to the PI polymer.

Polypropylene (PP) is a member of polyolefin's and one of the most widely used semi-crystalline thermoplastics with low density and low cost. PP-based parts are commonly used in different industries such as military, marine vehicles, packaging, household appliances, automobiles and constructions due to their physical and chemical properties. However, PP exhibits low thermal, electrical, and mechanical properties compared to other engineering plastics (PC, PA, etc.) and also a high coefficient of friction under dry sliding conditions. The simplest way to improve the mechanical and tribological properties of PP polymers is adding inorganic fillers in the form of nanoparticle [23–27]. Bettina *et al* [28] investigated the influence of carbon-based additives, such as, thermally reduced graphite oxide (TRGO), multi-layer graphene, carbon black (CB), MWCNT and expanded graphite (EG) with different particle sizes and shapes on the flame retardancy and mechanical properties of isotactic polypropylene (iPP). Suresha *et al* [29] investigated the effect of nanofillers on the mechanical and tribological properties of polyamide 66 and PP. Improvements in the mechanical and tribological behaviours were observed with the addition of the nanofillers.

It is anticipated that GO-filled composites may find large potential applications in different industries, not only for their excellent thermal and mechanical properties, but also for their potential friction and wear reduction. It was not encountered with any study that was investigated the tribological properties of GO-filled PP polymers. In the present study, GO-filled PP nanocomposites with and without PP-g-MA were prepared using extrusion and injection moulding process. Besides, the effect of GO addition on friction and wear behaviour of PP polymer, the effect of load and sliding speed was also investigated. Tribological tests were performed by using pin-on-disc machine against AISI 1040 steel disc at room temperature under dry conditions at 0.4, 0.8, 1.2 and 1.6 $\mathrm{m\,s^{-1}}$ sliding speeds and 10, 20, 30 and 40 N loads.

2. Experimental

In this study, PP polymer with density of $0.9\,\mathrm{g\,cm^{-3}}$ obtained from Exxonmobil Chemical Company (trade code: PP3374E3) was used as matrix material. As a reinforcement element, GO was purchased from Nanografen Co. (Turkey) with a bulk density, average number of layers and oxygen content of $0.022\,\mathrm{g\,ml^{-1}}$, 27 and 4.1%, respectively. As a compatibilizer agent, maleic-anhydride-grafted-polypropylene supplied from Addivant™ (trade code: PP3200). Figure 1 represents schematically the manufacturing of PP-g-MA and GO-filled PP nanocomposites. First, GO was dispersed in water by probe sonicator (30 min and 35% amplitude) to exfoliate graphene layers. This solution was mixed with PP polymer and then dried at 100°°C for 2 h before extrusion process. PP-g-MA and GO-filled PP nanocomposites granules were prepared with NRII-75-Werner-Pfleiderer model twin-screw extruder at 185−210°C. The specimens for tribological tests were produced using the injection–moulding machine (ERAT, Istanbul, Turkey). The injection heater temperatures were set as 190−220°C. The mould temperature was fixed at 30°C. With this procedure, the prepared samples with measured densities and Shore D hardness values and abbreviations are given in table 1.

Wear tests were performed by using pin-on-disc machine against AISI 1040 steel disc at room temperature (23°C ± 2 and 48 ± 2% humidity) under dry conditions. Samples with a diameter of 5 mm and a length of 50 mm were used for wear tests. Tribological tests were run at 0.4, 0.8, 1.2 and 1.6 $\mathrm{m\,s^{-1}}$ sliding speeds and 10, 20, 30 and 40 N loads. Figure 2 shows a schematic diagram of the pin-on-disc wear test machine that was designed and used for this work. The AISI 1040 steel discs were machined to 10 mm thickness and 60 mm diameter and ground to a surface roughness of 0.20−0.32 μm and a hardness value of 50–55 HRC. Wear rate (K_o) was

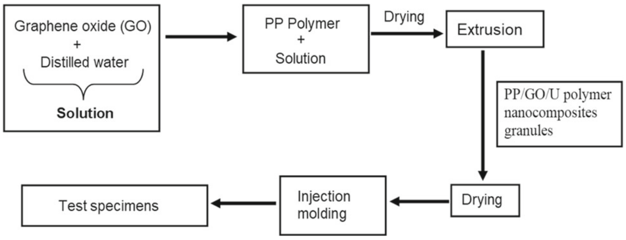


Figure 1. Manufacturing process of PP-g-MA and GO-filled PP nanocomposites.

Table 1. Produced samples, abbreviations and result of density and Shore D hardness of PP-g-MA and GO-filled PP nanocomposites.

No.	Formulation	Abbreviation	Density (g cm^{-3})	Hardness, Shore D
1.	Polypropylene	PP	0.8775	72.25
2.	Polypropylene + 0.05 wt% graphene oxide	PP+0.05GO	0.8793	72.29
3.	Polypropylene + 0.15 wt% graphene oxide	PP+0.15GO	0.8801	74.21
4.	Polypropylene + 0.05 wt% GO+ 3 wt% PP-g-MA	PP+0.05GO+3U	0.8702	71.68
5.	Polypropylene + 0.15 wt% GO+ 3 wt% PP-g-MA	PP+0.15GO+3U	0.8692	73.42

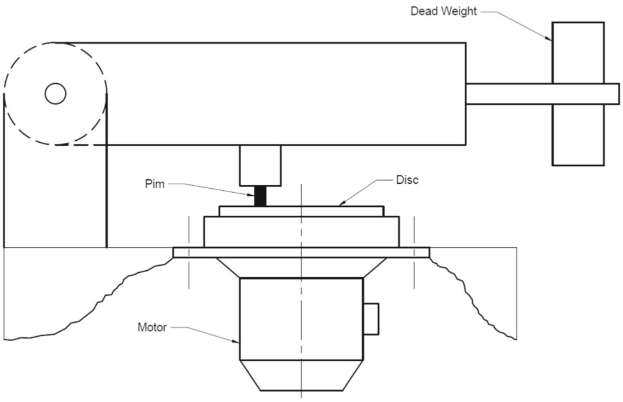


Figure 2. Wear test machine.

calculated using equation (1), where Δm, average weight loss (g); L, distance (m); F, the load (N); and ρ, density (g cm^{-3}). Each test was repeated three times and the close results were considered and their average values were presented.

$$K_o = \frac{\Delta m}{L * F * \rho}. \tag{1}$$

3. Results

As known, GO is a layered material that is characterized by strong interlayer covalent bonds within the graphite layers and weak van der Waals forces between the graphite layers [30]. Exfoliation causes the graphite layers to form an interconnected network structure, which is described as worm-like or accordion bellows character [30,31]. Figure 3 represents SEM images of GO flakes before and after the mixing process. The standard accordion-like structure of expanded GO can be seen in figure 3a. According to the supplier, BET surface area of expanded GO is about 11 m^2 g^{-1}. After the sonicator process, the formed GO structure is given in figure 3b.

The crystallization behaviour of PP nanocomposites was examined with X-ray diffraction analysis (XRD) analysis. XRD results showed the formation of α-phases, which were confirmed by the appearance of peaks at 110, 40, 111, 41, 60 and 220 at 13.9, 16.7, 18.4, 21.0, 25.3 and 28.3°, respectively (figure 4). The low intensity peak at $2\theta = 15.8^{\circ}$ corresponds to the (300) plane of the β-crystal form of PP/GO nanocomposite. The addition of GO into the PP polymer caused to change in its crystals forms. It shows that GO acted as a β-nucleating agent for PP/GO nanocomposites. This result is consistent with previous studies [32–34].

The mechanical properties of GO-filled polymeric nanocomposites depend on the dispersion of GO in the polymeric matrix and strong interfacial interaction between the GO and the polymer matrix [23,35]. It is clearly seen in table 2 that tensile strength and tensile modulus of unfilled PP increased after the addition of GO and this increment was more pronounced in the PP-g-MA filled PP/GO nanocomposites. The tensile modulus of PP+0.05GO and PP+0.15GO nanocomposites were about 10.3 and 25.9% higher than that of unfilled PP, respectively. This indicates that the stiffening effect of the GO on PP polymer is significant. Further increase in modulus was observed when PP-g-MA was added to the PP/GO nanocomposites because of exfoliation mechanism, which also restrained the matrix from deformation in the elastic region [36]. Similar results were obtained by Liang *et al* [37] and Menbari [38]. The increase of the modulus in the PP/GOs nanocomposite is due to the reinforcing effect of GO, whereas in the PP/PP-g-MA/GO nanocomposite, better dispersion of GOs in the PP matrix and an enhancement in interfacial interaction between PP and GO play the synergistic role. Moreover, the presence of PP-g-MA changed the polymer morphology and this also contributed to the tensile properties of the PP/PP-g-MA/GO nanocomposite [39]. Table 2 also shows the elongation at break and Izod impact strength of GO and PP-g-MA-filled PP nanocomposites. The values of elongation at break and Izod impact strength decreased outstandingly with increase in the GO weight fraction. These results indicated that the GO make PP loss toughness and become brittle [23].

Generally, the tribological properties of polymer composites are described with the friction coefficient and the specific wear rate [18,40]. Table 3 gives friction coefficient values, which were obtained from wear tests for PP and PP nanocomposites at 10–40 N loads and 0.4–1.6 m s^{-1} sliding speeds. Figures 5 and 6 show the variations in friction coefficient of PP and PP nanocomposites with different loads and sliding speeds, respectively. In figure 5, it can be seen that the friction coefficient increase with the increase of load for PP and its composites. Friction coefficients of PP, PP+0.05GO, PP+0.15GO, PP+0.05GO+3U and PP+0.15GO+3U polymer composites increased by 20.12,

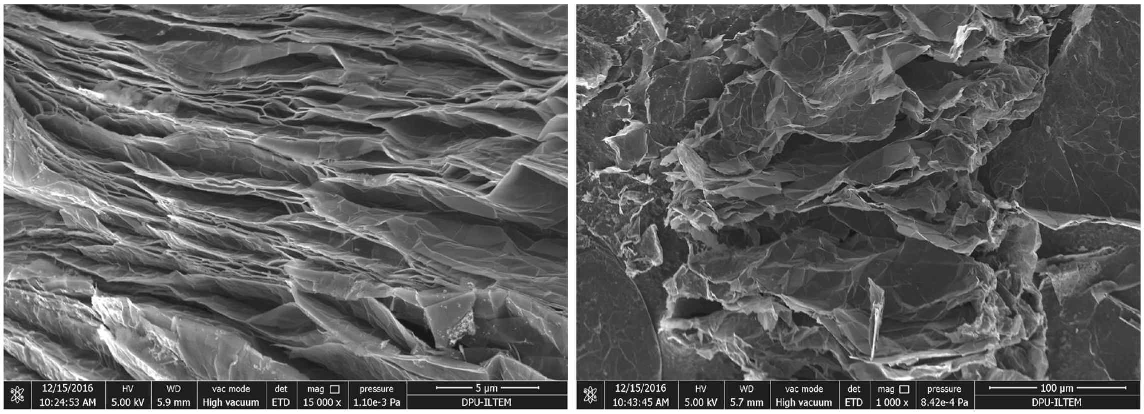


Figure 3. SEM images of GO before and after solution.

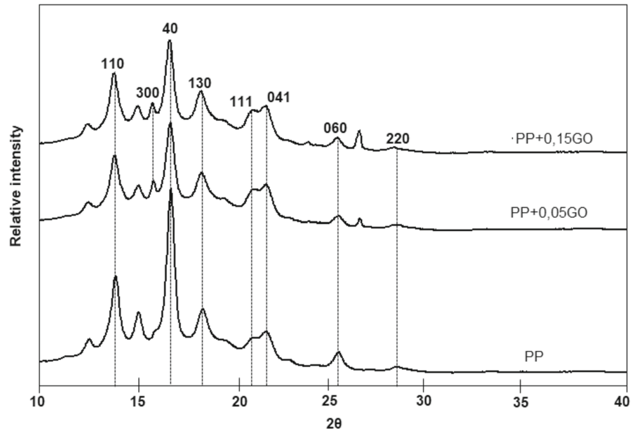


Figure 4. XRD patterns of PP and PP nanocomposites.

Table 2. Mechanical properties of PP-g-MA and GO-filled PP nanocomposites.

Materials	Tensile strength (MPa)	Tensile module (MPa)	Elongation at break (%)	Izod impact strength (kJ m^{-2})
PP	22.6	1028	48	27.4
PP+0.05GO	24.9	1211	25.2	12.4
PP+0.05GO+3U	26.0	1280	27.4	13.6
PP+0.15GO	28.4	1336	21.5	12.9
PP+0.15GO+3U	29.1	1414	23.8	14.2

Table 3. Friction coefficient values for PP and PP nanocomposites tested at loads and sliding speed.

		Sliding speed, m s^{-1}			
		0.4	0.8	1.2	1.6
Materials	Loads (N)	Coefficient of friction, μ			
PP	10	0.472	0,533	0,549	0,567
	20	0.544	0,604	0,631	0,643
	30	0.602	0,627	0,710	0,737
	40	0.619	0,665	0,731	0,769
PP+0.05GO	10	0.428	0.461	0.489	0.510
	20	0.500	0.520	0.579	0.600
	30	0.512	0.577	0.640	0.675
	40	0.543	0.609	0.675	0.702
PP+0.15GO	10	0.397	0.405	0.428	0.445
	20	0.445	0.464	0.510	0.535
	30	0.462	0.535	0.589	0.614
	40	0.479	0.568	0.640	0.663
PP+0.05GO+3U	10	0.301	0.326	0.330	0.345
	20	0.373	0.382	0.406	0.474
	30	0.437	0.496	0.502	0.569
	40	0.451	0.520	0.532	0.634
PP+0.15GO+3U	10	0.282	0.299	0.304	0.325
	20	0.309	0.317	0.334	0.434
	30	0.399	0.429	0.436	0.499
	40	0.419	0.438	0.418	0.542

19.15, 12.09, 14.59 and 15.52% with increase load, respectively. When the GO content increased, the coefficient of friction of PP nanocomposites decreased. Friction coefficient of PP-g-MA and GO-filled PP nanocomposites decreased by 8.2, 14.2, 37.3 and 74.7% when compared unfilled PP under 1.2 m s^{-1} sliding speed and 40 N load. Similar results were obtained by Song [2], Kandanur [41], Yan [42], Yuanshi [22] and Padenko [43]. This is on account of the homogeneous dispersion of GO and superior tribological properties of multi-layered GO [44]. Furthermore, in a study performed in the literature [19], the excellent friction properties of GO-filled polymer composites were based on self-lubrication properties of GO, which has played a significant role in reducing friction coefficient by reducing the shear force. In a study performed by Mindivan [45], the reduction in the coefficient of friction was explained by the XRD analysis results. A larger number of graphene sheets were obtained by adding more graphene nano-platelet (GNP) into the PA6 matrix. It

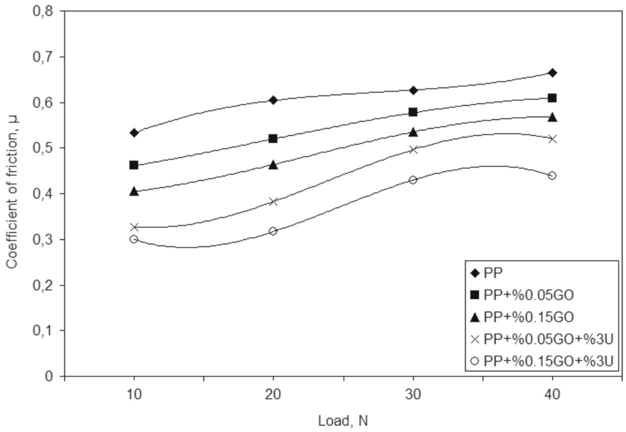


Figure 5. Friction coefficient of PP and PP nanocomposites according to loads (sliding speed: 0.8 m s^{-1}).

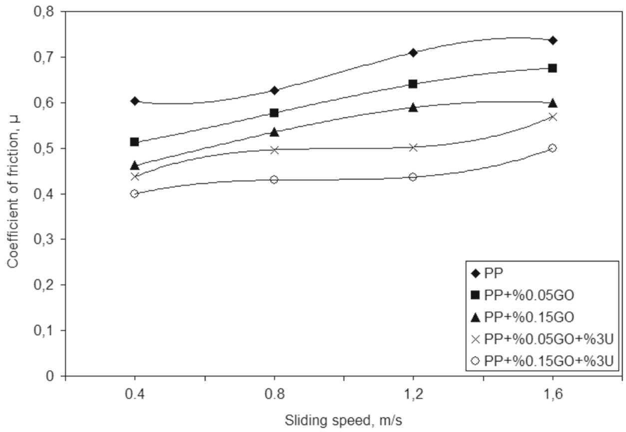


Figure 6. Friction coefficient of the PP and PP nanocomposites according to sliding speed (load: 30 N).

was stated that there was a small increase in the basal spacing (peak was shifted to the right) of the composite with increasing GNP. These differences likely to influence the tribological behaviour. They pointed out that the van der Waals forces in the high GNP-filled PA6 composite would be lower than the low GNP-filled PA6 composites and thus, the GNP layers would slide much more easily over each other. When figure 6 was examined, it was founded that the friction coefficient increased due to increased sliding speed. This increase was 22.28% for PP polymer, 31.83% for PP+0.05GO polymer, 32.90% for PP+0.15GO polymer, 32.59% for PP+0.3GO polymer and 37.79% for PP+0.5GO polymer. Song *et al* [2] found that the changes of friction coefficient and wear rates, which depend on sliding speed, were tightly concerned with friction-induced heat. They pointed out that this heat plays a much more important role in friction interface at high sliding speed according to low sliding speed. Consequently, for the range of applied loads and sliding speeds, the lowest coefficient of friction values are obtained in PP+0.15GO+3U polymer nanocomposites.

The effect of GO on the wear rate of PP and PP nanocomposites under 1–40 N loads and 0.4−1.6 m s^{-1} sliding speeds are illustrated in table 4. In general, the wear rate for PP and PP nanocomposites were 10^{-13} m^2 N^{-1}. In the sliding speed and load range of this study, the minimum wear rate was obtained for 0.15% GO and 3% PP-g-MA-filled PP nanocomposites with a value of 5, 7537E^{-14} m^2 N^{-1} at 0.4ms^{-1} sliding speed and 10 N load. The maximum wear rate was obtained in the PP polymer under 40 N load and 1.6 m s^{-1} sliding speed. At 1.6 m s^{-1} sliding speed and 10 N load, the wear rates of PP+0.05GO, PP+0.15GO, PP+0.05GO+3U and PP+0.15GO+3U were 6.12, 21.3, 91.3% and 105.7%, respectively, and were lower than that of PP. Figures 7 and 8 show the change in wear rate with test load and sliding speed. As it is shown in the graphs, wear rate increased with increasing both load and sliding speed. It is believed that the increase in the friction coefficient and wear rate is owing to the rise in surface temperature. This temperature reaches softening point of the polymer resulting in high wear rates. Wang *et al* [46] declared that the increased wear rate of multi-layer graphene (MLG)/PVC nanocomposites was linked to the formation of wear debris under dry sliding conditions with respect to the high self-lubrication properties of multilayered graphene and increased toughness of nanocomposite. Furthermore, the presence of multilayered graphene, crack initiation was inhibited, a protective film layer was formed, microcrack initiation and growth were prevented, and as a result, under sliding conditions, wear resistance of nanocomposites increased.

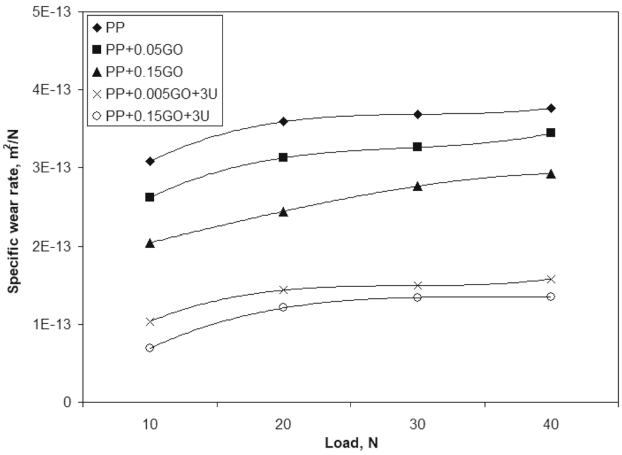


Figure 7. Wear rate of the PP and PP nanocomposites according to loads (sliding speed: 0.8 m s^{-1}).

Figure 9 shows the correlation between friction coefficient and sliding distance for PP polymer and PP-g-MA and GO-filled PP polymer nanocomposites tested under 0.8 m s^{-1} sliding speed and 30 N load. As it is shown in the graph, change in the friction coefficient of PP polymer and PP nanocomposites occurred in two stages as initial and steady-state conditions. In the first stage, the coefficient of friction increased rapidly. In the second stage called as steady-state,

Table 4. Wear rate values for PP and PP nanocomposites tested at loads and sliding speed.

Material	Load (N)	Sliding speed (m s^{-1})			
		0.4	0.8	1.2	1.6
		Wear rate (m^2 N^{-1})			
PP	10	$2.394E^{13}$	$3.078E^{-13}$	$3.534E^{-13}$	$3.990E^{-13}$
	20	$2.793E^{-13}$	$3.591E^{-13}$	$3.933E^{-13}$	$4.161E^{-13}$
	30	$3.154E^{-13}$	$3.686E^{-13}$	$4.218E^{-13}$	$4.484E^{-13}$
	40	$3.335E^{-13}$	$3.762E^{-13}$	$4.332E^{-13}$	$4.618E^{-13}$
PP+0.05GO	10	$2.047E^{-13}$	$2.616E^{-13}$	$3.071E^{-13}$	$3.640E^{-13}$
	20	$2.502E^{-13}$	$3.128E^{-13}$	$3.469E^{-13}$	$3.868E^{-13}$
	30	$2.730E^{-13}$	$3.261E^{-13}$	$3.868E^{-13}$	$4.209E^{-13}$
	40	$2.929E^{-13}$	$3.441E^{-13}$	$3.924E^{-13}$	$4.351E^{-13}$
PP+0.15GO	10	$1.590E^{-13}$	$2.045E^{-13}$	$2.386E^{-13}$	$2.954E^{-13}$
	20	$1.931E^{-13}$	$2.443E^{-13}$	$2.954E^{-13}$	$3.125E^{-13}$
	30	$2.310E^{-13}$	$2.765E^{-13}$	$3.181E^{-13}$	$3.484E^{-13}$
	40	$2.386E^{-13}$	$2.926E^{-13}$	$3.267E^{-13}$	$3.806E^{-13}$
PP+0.05GO+3PP-g-MA	10	$6.896E^{-14}$	$1.034E^{-13}$	$1.379E^{-13}$	$1.724E^{-13}$
	20	$8.045E^{-14}$	$1.436E^{-13}$	$1.551E^{-13}$	$1.954E^{-13}$
	30	$1.034E^{-13}$	$1.494E^{-13}$	$1.762E^{-13}$	$2.337E^{-13}$
	40	$1.264E^{-13}$	$1.580E^{-13}$	$1.810E^{-13}$	$2.413E^{-13}$
PP+0.15GO+3PP-g-MA	10	$5.753E^{-14}$	$6.904E^{-14}$	$1.265E^{-13}$	$1.611E^{-13}$
	20	$6.904E^{-14}$	$1.208E^{-13}$	$1.380E^{-13}$	$1.668E^{-13}$
	30	$9.589E^{-14}$	$1.342E^{-13}$	$1.419E^{-13}$	$2.148E^{-13}$
	40	$9.781E^{-14}$	$1.352E^{-13}$	$1.524E^{-13}$	$2.243E^{-13}$

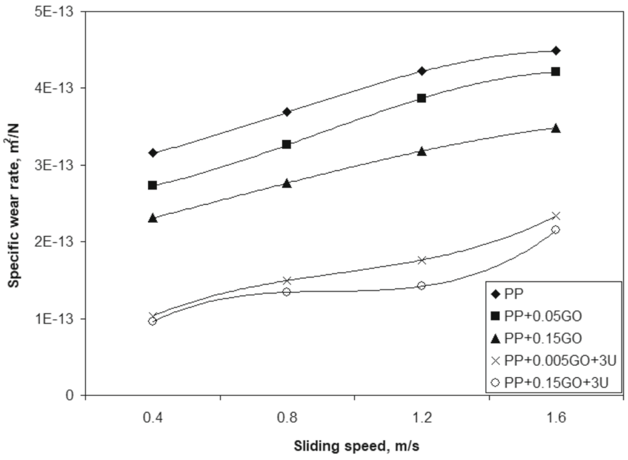


Figure 8. Specific wear rate of the PP and PP nanocomposites according to sliding speed (load: 30 N).

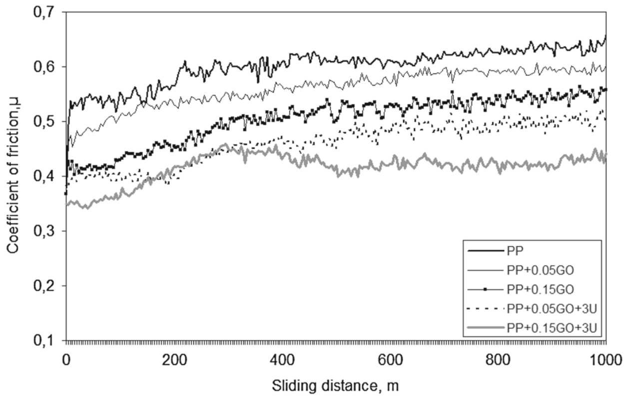
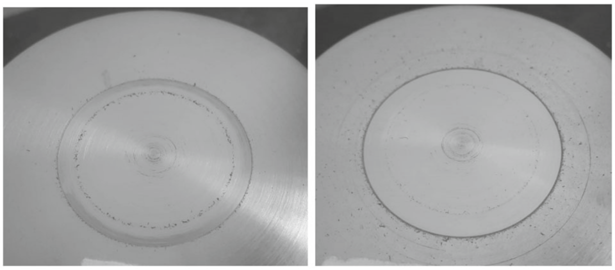
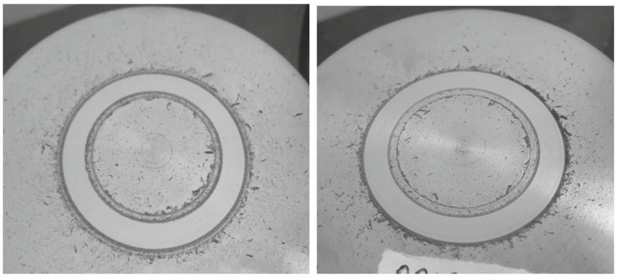


Figure 9. Friction coefficient-sliding distance of PP polymer and PP nanocomposites (sliding speed: 0.8 m s^{-1}, load: 30 N).

the coefficient of friction of the PP polymer and PP nanocomposites attained a stable value after about 300 m sliding distance. The coefficient of friction for the PP polymers was obtained between 0.4 and 0.62, while the coefficient of friction of PP nanocomposites is reduced to the value of 0.3–0.52. The same trend was obtained by Tai *et al* [18] and Song *et al* [2]. Samyn and Schoukens [47] attributed the reduction of the coefficient of friction to geometric effects, deformation and the formation of the transfer film layer. When the disc images were examined in figure 10, it was observed that there was a transfer film layer and wear debris, which reduces the friction between pin and disc. Therefore, the friction coefficient of nanocomposites decreased because of the emergence of the transfer film, which reduced the direct contact between the matrix and counter disc. Padenko [43] also explained that the reduction in the coefficient of friction is due to the



PP PP+0.05GO



PP+0.15GO PP+0.05GO+3U

Figure 10. Macro pictures of disc surface of PP and PP nanocomposites.

self-lubrication behaviors of GO and the formation of the transfer film on the disc surface under dry sliding conditions. Polymer nanocomposites have superior friction properties due to the fact that GO has small dimensions, thin layer structure and excellent self-lubrication properties. This plays an important role during friction tests in reducing the shear force and in the formation and preservation of low friction [19].

4. Conclusion

In the experimental study, the following conclusions can be drawn depending on experimental mechanical, and friction and wear results.

Tensile strength and tensile modulus of unfilled PP increased after the addition of GO and this increment was more pronounced in the PP-g-MA-filled PP/GO nanocomposites. The tensile modulus of PP+0.05GO and PP+0.15GO nanocomposites was about 10.3 and 25.9% higher than that of unfilled PP, respectively. The coefficient of friction for PP-g-MA and GO-filled PP nanocomposites increased with load and sliding speed. Wear rate increased with load and sliding speed for GO-filled PP nanocomposites. The average specific wear rates were obtained with a value of 10^{-13} m^2 N^{-1} for GO-filled PP composites. Both friction coefficient and wear rate of GO-filled PP nanocomposites are significantly reduced. The best friction coefficient and wear rate were obtained in PP-g-MA and GO-filled PP polymer nanocomposites. The friction coefficient and wear rate of PP nanocomposites were affected by the formation of the transfer film on the disc surface. Consequently, PP-g-MA and GO-filled PP polymers can be concluded as promising candidates for using in different engineering applications.

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