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Research Article

Tribological properties of PPS/PA46 polymer blends

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Abstract

In this study, the tribological performance of originally 40 wt.% fiber glass reinforced polyphenylene sulfide (PPS-G), polyamide 46 (PA46) and their blends were studied at dry sliding conditions. The materials were mixed and extruded on the twin screw extruder. The blends were dried and tribological test specimens were manufactured by using the injection machine. Wear tests were performed with the configuration of a polymer pin on a rotating X40CrMoV5-1 steel disc. Test conditions were atmospheric conditions having 60, 90, 120 N loads and 0.5, 1.0, 1.5 m/s sliding speeds. The obtained results proved that the coefficient of friction for PPS-G, PA46 and their blends is decrease while the applied load and sliding speed values are increase. On the other hand, the specific wear rate is in increase while the applied load and sliding speed values are in increase.

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1. Introduction

Polyphenylene sulfide (PPS) is a semi crystalline high-performance engineering thermoplastic polymer with excellent properties such as high temperature performance, heat resistance, chemical resistance, electrical insulation, high dimensional stability, good mechanical properties and flame retardancy without additives [1-5]. This property of PPS makes it popular in various applications including electronics and electrical appliances, automobile, chemical sector and aerospace [6-10]. However, the application of PPS has been limited due to its relatively low glass transition temperature (~ 90 °C), rather brittle with a low elongation at break and high cost [1, 2, 5, 7, 8, 11, 12]. In order to overcome these problems, PPS was blended with other polymers or reinforced with rigid particles [5, 11]. Polyamides (PAs) such as PA6, PA46 and PA66 are generally investigated for their wear performance [4, 12-14]. Among them, the chemical structure of PA46 offers an advantage compared to PA6 and PA66 [15].

The tribological performance of polymers and polymer blends are directly related to the test parameters like loads, sliding speed and distance and transfer film properties [16, 17]. The effect of test conditions on friction and wear behavior properties of PA, PPS and their composites have been reported in earlier papers [4, 12, 18]. Chen et al. [12] investigated the mechanical and tribological properties of PA66 and PPS blends. Tribological test was performed under ambient conditions at a speed of 0.42 m/s and a normal load of 196 N.

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They pointed out that the minimum wear volume was obtained in the case of PA66/PPS (80/20) blend and the wear volume of blends increased with PPS proportion after the PPS content exceeds 20 vol. %. Zhou et al. [4] investigated the effect of carbon fiber (CF) on mechanical and tribological performance of the PA6/PPS composites. The friction and wear tests were carried out under 10 N, 15 N and 20 N loads and 500, 1000 and 1500 rpm/min rotate speeds, for a duration of 40 min. Under the friction condition of high applied load or high sliding speed, friction coefficient of the PA6/PPS-CF composites tends to decrease, and wear rate tends to increase. Zhao and Bahadur [18] investigated the tribological behaviors of the particulates NiS and PbSe filled polyphenylene sulfide (PPS) composites under ambient conditions in a pin-on-disk configuration at a sliding speed of 1.0 m/s and a nominal pressure of 0.65 MPa. Cho [19] studied the role of transfer films formed during the sliding of PPS/CuO/CF/Kevlar polymer composites against the steel counter face. It was reported that as far as the transfer film became smooth and uniform, the wear rate decreased. Cho et al. [20] studied the tribological behavior of molybdenum-concentrate (MC) filled polyphenylene sulfide (PPS). They reported that MC, as the filler in particulate form, reduced the steady state wear rate of PPS, and the optimum reduction in wear was found to occur with the addition of polytetrafluoroethylene (PTFE) along with PPS. Cong et al. [13] investigated the tribological properties of PA46/HDPE poly blend with different component ratios. They reported that HDPE was effective in reducing the friction coefficient of PA46 and specific wear rate of PA46/HDPE poly blend decreased with increasing HDPE content. Scherge et al. [14] investigated the wear characteristics of aliphatic PA 46 on lubricated steel disk. They declared that under certain boundary parameters at transfer film forms and significantly improvement wear performance. Yu et al. [21] studied the friction and wear behaviors of polyamide 66 (PA 66) and rubber-filled PA 66 (PA 66/SEBS-*g*-MA) composites on a block-on-wheel model friction and wear tester under dry sliding and water lubricating conditions. The friction coefficients of PA 66 and PA 66/SEBS-*g*-MA composites under water lubricating condition were lower than those under dry sliding condition, but the wear mass losses were higher than those under dry sliding condition. It is seen from the literature that the majority of the investigations confined their discussions to dry sliding condition.

It is known that high thermal resistant polymer such as PPS and PA46 are used in automotive industry as products (such as fuel injection systems, air intake manifold, coolant systems, water pump impellers, thermostat holder, electric brakes, switches, bulb housing and so on) that work under the effects of temperature and pressure [22-25]. And, at the same time, they remain in constant friction with other metal and polymer materials with which they are in contact, both due to engine vibration and road shock. Although their usage is increasingly widespread there is no enough study about on the tribological properties of PA/PPS polymer blends. So, in this study these two high temperature polymers that are widely used in industry are selected and the influence of sliding speed and load values on the friction and wear characteristics of PA46, PPS-G (originally glass fiber reinforced PPS) and their blends were studied.

2. Material and Method

The selected materials polyamide 46 (Stanyl PA46) with 1.18 g/cm³ density was supplied from Royal DSM (Holland) and 40 wt.% glass fiber filled PPS (PPS S25G40) with 1.57 g/cm³ density was supplied from Kolon Plastic Inc. (China). PPS/PA46 blends were manufactured on AYSALAB30 model, was given in Fig. 1.a, co-rotating double screw extruder machine in the following volume ratios: 100/0; 90/10; 80/20; 50/50 and 0/100. The extruder temperatures from the feed zone of polymer to the exit die were 275, 280, 288, 295 and 300 °C, respectively. The extruder exit die diameter is 4 mm and the screw speed was 70 rpm. The polymers were dehumidified at 140 °C for 4 hours before extrusion. The extruded

polymer mix material pelletized in the crusher. Thereafter, the injected samples (Fig.1.c) for wear tests were produced using the injection machine Demag Stübbe S110, which was given in Fig. 1.b at 500 bar injection pressure. The injection temperatures from the feed zone to the exit nozzle were 275, 285, 295, 300 and 300 °C. The screw speed was 80 cm³/s and the mould temperature was 30 °C.

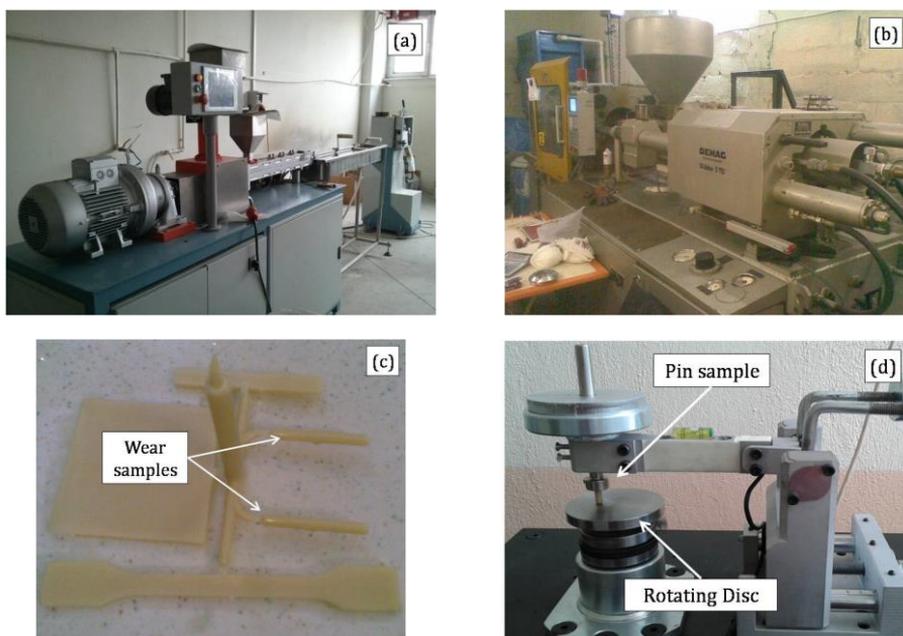


Fig.1.a) AYSA LAB30 co-rotating twin-screw extruder, b) DemagStübbe S110 injection-molding machine, c) Injected test samples, d) Pin-on-disc wear test rig.

Fig. 1.d shows the pin-on-disc wear test rig. The wear tests were performed at room temperature with non-lubrication or any wetting system. Materials and the specific test conditions (i.e. materials, ambient temperature, applied load, sliding speed and humidity) selected for this study were summarized in Table 1.

Table 1 Properties and specific test parameters of the PPS-40GF, PA46 and their blends.

Materials	Density (g/cm ³)	Applied load (N)	Sliding speed (mm/s)	Temperature (°C)	Humidity (%)
PPS-G	1.57				
PPS-G/10%PA46	1.51				
PPS-G/20%PA46	1.42	60, 90, 120	0.5, 1.0, 1.5	22±3	50±5
PPS-G/50%PA46	1.34				
PA46	1.18				

As is known, polymer materials generally work against metal materials in terms of their use. Therefore, in this study, medium carbon steel (AISI 1040) material was chosen as the counter disc surface. The disc of the wear test rig had 100 mm diameter and 5 mm thickness. The cylindrical polymer pin samples had 5 mm diameter and 50 mm length. Before the wear test, the samples contact surfaces were processed at 1000 grade paper. In addition, both disc and sample surfaces were cleaned with alcohol and then dried quickly.

All tests were performed in three times and their averages results were taken. The average mass loss in the pin was measured and the specific wear rates were calculated.

3. Results and Discussion

Table 2 gives the coefficient of friction results for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers according to the test parameters. The coefficient of friction is expressed as the ratio of lateral force to normal applied force and is calculated by Eq. 1.

$$\mu = \frac{F_S}{F_N} \quad (1)$$

Here; μ is friction coefficient, F_S is lateral friction force and F_N is normal applied force.

Table 2 Average coefficient of friction values for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers tested at different load and sliding speed values.

Materials	Load (N)	Sliding speed (m/s)		
		0.5	1.0	1.5
Coefficient of friction (μ)				
PPS-G	60	0.2853	0.2601	0.2495
	90	0.2784	0.2248	0.1956
	120	0.2566	0.2018	0.1822
PPS-G/10%PA46	60	0.3234	0.2916	0.2687
	90	0.3042	0.2413	0.2225
	120	0.2778	0.2239	0.2011
PPS-G/20%PA46	60	0.3467	0.3266	0.3033
	90	0.3294	0.2824	0.2571
	120	0.3018	0.2591	0.2375
PPS-G/50%PA46	60	0.4144	0.3786	0.3484
	90	0.3866	0.3274	0.2966
	120	0.3412	0.3024	0.2856
PA46	60	0.4823	0.4461	0.4192
	90	0.4266	0.3808	0.3515
	120	0.3908	0.3644	0.3264

The variation of the coefficient of friction with sliding distance for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers performed under 90 N load and 1.0 m/s sliding speed is given in Fig. 2. It is clearly seen from this graph, that the coefficient of friction curves for PPS-G, PA46 and their blends increases rapidly beginning the test at running-in period and reaches more stable course within the steady state period. During the running-in period, wear debris are formed between the contact surface, and the wear debris become compacted and adhered on the disc surface lowering coefficient of friction in the steady-state period [26]. Similar results were obtained by Chen et. al [12] and Zhou et. al [4].

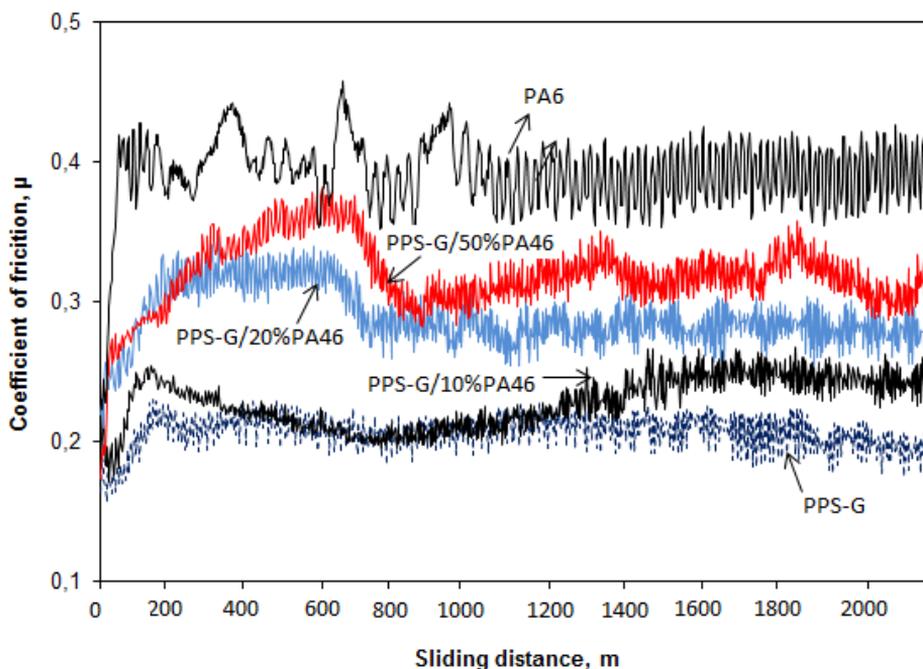


Fig. 2 Variation of coefficient of friction with sliding distance for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers (sliding speed: 1:0 m/s, Applied load: 90N).

If the chart is carefully considered, the overall trend for the coefficient of friction of PA46/PPS-G blends is similar, but coefficient of friction of PA46 is quite high than the PPS-G and PPS-G/PA46 blends, especially in the steady state. It was found that the coefficient of friction for PPS-G and PA46/PPS-G blends and for PA46, was between 0.2-0.35 and was 0.4 respectively.

Figs. 3 and 4 gives the variation of the coefficients of friction for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers accordance to the applied load and sliding speeds, respectively. In Fig. 3 for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers at 1.0 m/s sliding speeds, the coefficient of friction decreases linearly while the load increases. These results are adjusted with the past studies which had been completed by Unal [27], Yuji [28], Jiang [29], Zhou [4] and Wang [16]. In the case of PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46, there is an average decrease result 22%, 23%, 21%, 20% and 18% in the coefficient of friction values while the applied load increases, respectively. The contact temperature between polymer and steel disc surfaces increased because of the increase in the applied load, which resulted in two different effects on the coefficient of friction. The first one, the real contact area increased between surfaces and then the coefficient of friction increased. The second, the shear strength decreased and thus the coefficient of friction decreased [16].

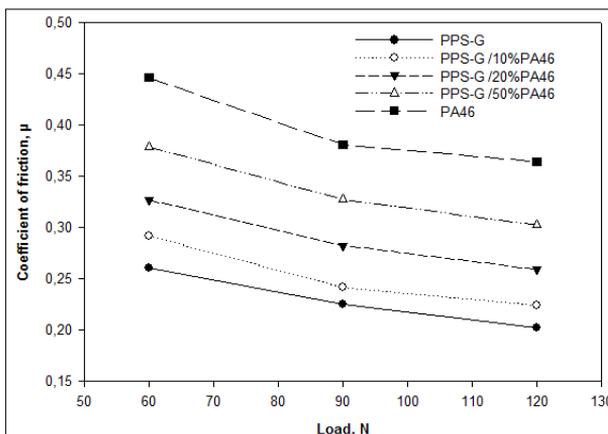


Fig. 3 Variation of coefficient of friction with applied load for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers (Sliding speed: 1.0 m/s).

In Fig. 4 for PPS-G, PA46 and their blends at 90 N applied load, the coefficient of friction decreases linearly while the sliding speed increases. For PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46, there is an average decrease of approximately 30%, 26%, 21%, 23% and 17% in the coefficient of friction values while the sliding speed increase from 0.5 m/s to 1.5 m/s. It is clear from these graphs that the sliding speed influence is much higher than the applied load. The similar results were obtained by Zhou [4] and Zhang [24]. Furthermore, with the increase of the content of PA46 polymer, the coefficient of friction of PPS-G/PA46 blends increases.

Table 3 shows the specific wear rate and weight loss values in PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers tested under 60, 90 and 120 N load, at 0.5, 1.0 and 1.5 m/s speeds and for 2000 m sliding distance. To determine the wear rate of the materials, the samples are weighed with a precision scale before and after the wear test. By calculating the difference between the initial weight and the final weight, the wear loss value of the sample is found for the determined conditions. The wear loss value is used to find the specific wear rates of materials by using the formulation in Eq. 2.

$$W_a = \frac{\Delta_m}{S \cdot \rho \cdot F_N} \tag{2}$$

Here, W_a is wear rate, Δ_m is wear loss, S is slide distance, ρ is density of materials and F_N is normal force.

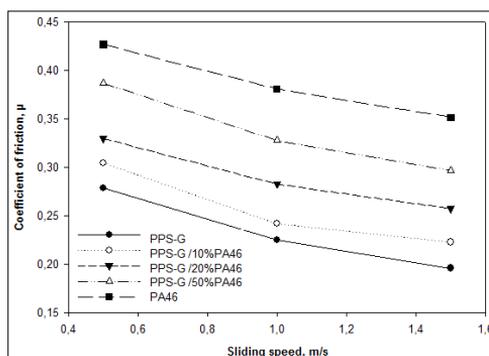


Fig. 4 Variation of coefficient of friction with sliding speed for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers (Applied load: 90 N).

Table 3 Specific wear rates and weight loss values for PPS, PPS/10%PA46, PPS/20%PA46, PPS/50%PA46 and PA46 polymers tested at different load and sliding speed values.

Materials	Load (N)	Speed (m/s)					
		0.5			1.5		
		Weight loss (g)			Specific wear rate (m ² /N)		
PPS-G	60	0,0017	0,0019	0,0021	9.023E ⁻¹⁵	1.008E ⁻¹⁴	1.114E ⁻¹⁴
	90	0,0031	0,0042	0,0049	1.096E ⁻¹⁴	1.486E ⁻¹⁴	1.733E ⁻¹⁴
	120	0,0044	0,0061	0,0071	1.167E ⁻¹⁴	1.618E ⁻¹⁴	1.884E ⁻¹⁴
PPS-G/10%PA46	60	0,0027	0,0029	0,0034	1.490E ⁻¹⁴	1.600E ⁻¹⁴	1.876E ⁻¹⁴
	90	0,0043	0,0049	0,0056	1.582E ⁻¹⁴	1,802E ⁻¹⁴	2.060E ⁻¹⁴
	120	0,0061	0,0072	0,0084	1.683E ⁻¹⁴	1.986E ⁻¹⁴	2.317E ⁻¹⁴
PPS-G/20%PA46	60	0,0035	0,0037	0,0041	2.053E ⁻¹⁴	2.171E ⁻¹⁴	2.406E ⁻¹⁴
	90	0,0054	0,0058	0,0066	2.112E ⁻¹⁴	2.269E ⁻¹⁴	2.582E ⁻¹⁴
	120	0,0078	0,0091	0,0104	2.288E ⁻¹⁴	2.670E ⁻¹⁴	3.051E ⁻¹⁴
PPS-G/50%PA46	60	0,0039	0,0046	0,0051	2.425E ⁻¹⁴	2.860E ⁻¹⁴	3.171E ⁻¹⁴
	90	0,0062	0,0073	0,0085	2.570E ⁻¹⁴	3.026E ⁻¹⁴	3.524E ⁻¹⁴
	120	0,0084	0,0103	0,0117	2.611E ⁻¹⁴	3.202E ⁻¹⁴	3.638E ⁻¹⁴
PA46	60	0,0041	0,0051	0,0059	2,895E ⁻¹⁴	3.601E ⁻¹⁴	4.166E ⁻¹⁴
	90	0,0063	0,0079	0,0092	2.961E ⁻¹⁴	3.719E ⁻¹⁴	4.331E ⁻¹⁴
	120	0,0086	0,0108	0,0124	3.036E ⁻¹⁴	3.813E ⁻¹⁴	4.378E ⁻¹⁴

Figs. 5 and 6 illustrate the variation of specific wear rate accordance to the applied load and sliding speed, respectively. In general, the specific wear rate for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers were in the order of 10^{-14} m²/N. The lowest wear rate is for PPS-G with a value of 9.02×10^{-15} m²/N while the highest wear rate is for PA46 with a value of 4.37×10^{-15} m²/N. The wear rates of PA46, PPS-G/10%PA46, PPS-G/20%PA46 and PPS-G/50%PA46 are 60, 51, 38 and 18 times lower than that of PPS-G at 1.0 m/s sliding speed and 90 N applied load, respectively. For PPS-G and its blends performed in this study within the applied load range of 60–120 MPa, the specific wear rates are increased with the increase in the applied load.

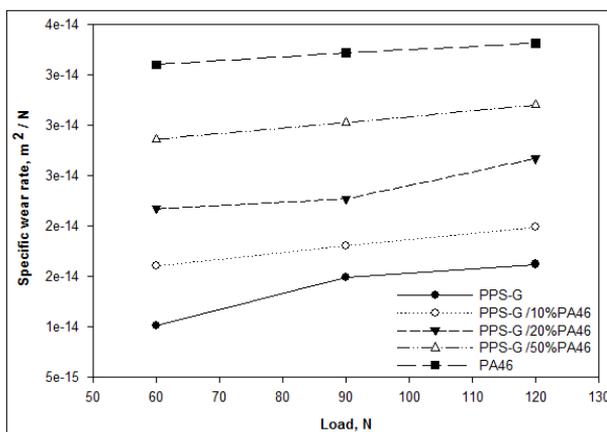


Fig. 5 Variation of specific wear rate with applied load for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers (Sliding speed: 1.0 m/s).

In Fig. 6 the specific wear rate values for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers increase linearly while the sliding speed increases. In case of PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46, there are about 36%, 23%, 18%, 27% and 31% increase in specific wear rate from 0.5 m/s to 1.5 m/s in the sliding speed at 90 N applied load, respectively. All the findings clearly match with the earlier studies results obtained by Unal [30], Zhang et al. [26] and Wang et al. [16].

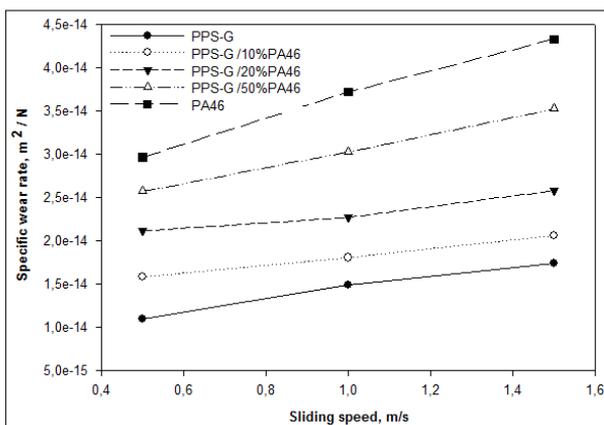
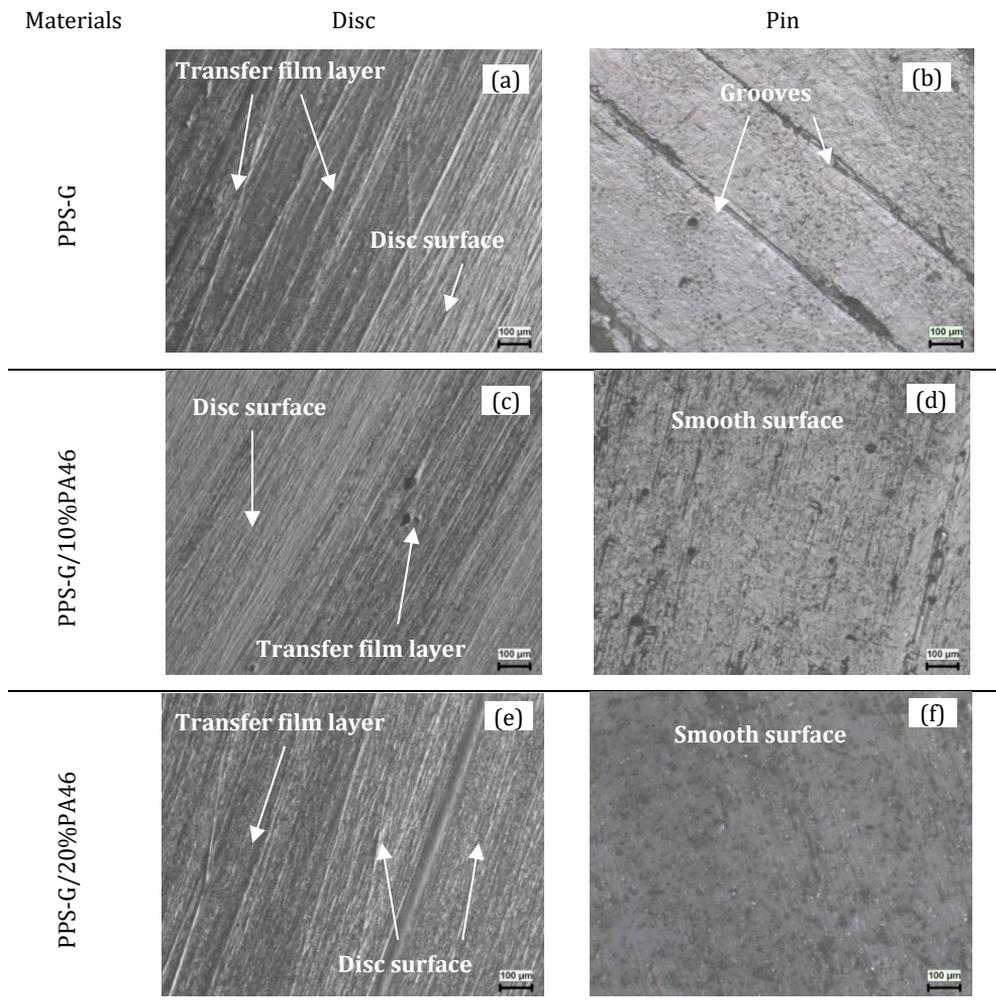


Fig. 6 Variation of specific wear rate with sliding speed for PPS-G, PPS-G/10%PA46, PPS-G/20%PA46, PPS-G/50%PA46 and PA46 polymers (Applied load: 90N).

The optical microscopy examination, as seen on Fig. 7 of the pin and disc surfaces of PPS-G, PA46 and their blends in dry conditions, at 60 N load and at 1.0 m/s sliding speed are given in Fig. 7. It is clear from the disc surface (in Fig. 7.a) that a good transfer film layer was formed for PPS-G polymer while the transfer film layer got worse with the increase of the content of PA46 (in Fig. 7.h). In the PPS-G polymer, the transfer film layer was effective on the entire surface, whereas in the PA46 added PPS-G blends; the transfer film layer was irregularly and locally shaped. This is thought to be due to the high specific wear rate of the PA46 polymer and increases the PPS-G blends specific wear rate with the addition increasing amount of PA46. For PA46 pin materials (in Fig. 7.j), the tested surface of the samples showed that the slip was occurred with wider and deeper grooves. However, these grooves were reduced in the PPS-G polymer due to the homogeneous transfer film layer. While a softer surface was obtained in the PPS-G/10%PA46 and PPS-G/20%PA46 blends, it was determined that numerous grooves were formed in the shear direction due to the increasing amount of PA46. The increased friction heat and deformed transfer film layer may deteriorate the tribological properties of PPS-G/PA46 blends. Consequently, the formation of the transfer film layer on the counter disc affected the wear and friction mechanism of PPS-G/PA46 blends.



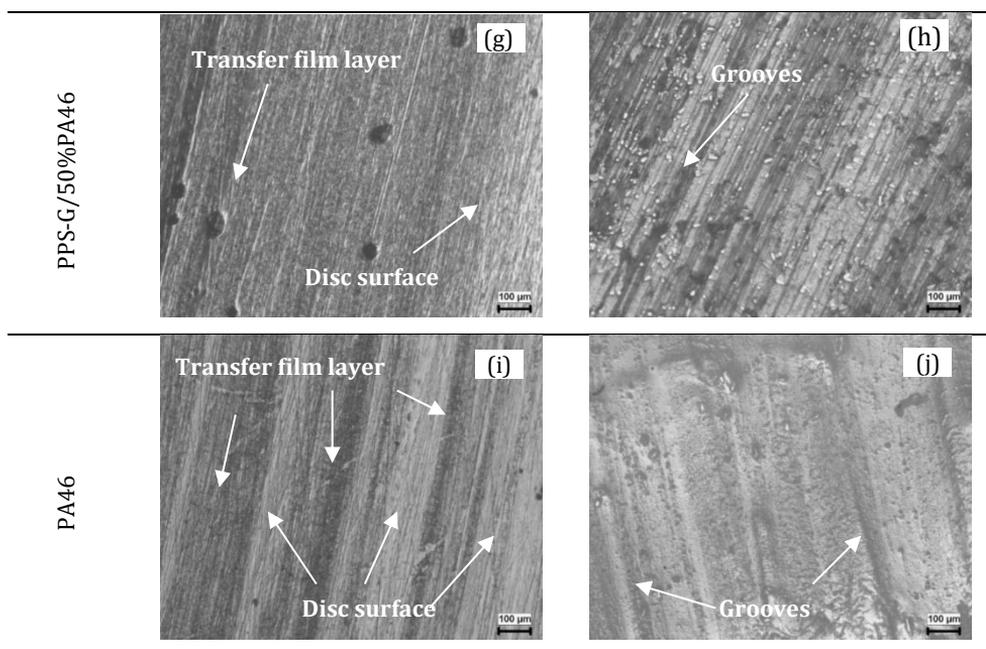


Fig. 7 Microscopy of pin-and disc surfaces of PPS-G, PA46 and their blends.

4. Conclusions

The tribological performance test of originally 40 wt.% fiber glass reinforced polyphenylene sulfide (PPS-G) and polyamide 46 (PA46) blends reveals the following conclusions:

The wear rates of PA46, PPS-G and their blends were in the order of 10^{-14} m²/N.

According to the applied load and sliding speed parameters, the friction coefficient values decrease while specific wear rates of PA46, PPS-G and their blends increase. Although the coefficient of friction is decrease, the high coefficient of friction of PA46 polymer and its negative effects on the PPS-G blends are clearly seen.

The highest specific wear rate was with a value of 4.37×10^{-14} m²/N for PA46 and the lowest wear rate was with a value 9.02×10^{-15} m²/N for PPS-G polymer. As the amount of PA46 increases, the specific wear rates of PPS-G blends also increase.

When the general tendencies investigated, changes in sliding speed had the greatest effect on friction coefficient and specific wear rate, that is, the biggest impact factor was the sliding speed.

All the coefficient of friction and specific wear results of the produced polymer blend varies between the values of neat PPS-G and PA46 materials according to the addition percentage.

The transfer film layer affects the wear and friction mechanism of PPS-G/PA46 blends.

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