Wear Behavior of Polytetrafluoroethylene and Its Composites in Dry Conditions

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Abstract In this paper, we investigated the friction and wear behavior of PTFE, bronze, and carbon filled PTFE polymers. Friction and wear tests were done on the Pin on Disc machine. The tests were carried out at load 10, 20, 30 N at a speed of 0.35, 0.66, 0.98 m/s at time intervals. The results show that the friction coefficient in PTFE and its composites decreases with an increase in load. The maximum wear and friction were seen at PTFE and 20% glass fiber. Adding bronze and fillers of carbon to PTFE found reduced wear. It has been found that speed has less influence on wear compare to load at high values.

Keywords PTFE · Friction · Wear · Polymer

1 Introduction

Polymers and their composite based are used widely to slide against metals, polymers, and other materials. The friction in polymer generates deformation and adhesion [1–3]. Mechanism of deformation involves complete dissipation of the contact area while adhesion generates friction in polymer and breaks the weak bonding between materials. There are different types of materials in polymers such as PP, PVC, PMMA etc among these, the performance shows better in smooth molecular polymer profiles [4, 5].

In today's era, PTFE is widely used in industry due to its self-lubrication property, high-temperature stability, less friction coefficient, and high chemical resistance. Actually, if we take PTFE only its exhibits high wear and friction but if it is added with additives and fillers such as reinforcement with glass fibers, carbon fibers, and solid lubricants, this will minimize problems [6–9]. Friction is reduced and wear resistance is highly improved when additives are added in polymer with carbon fibre

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and aramid fibre [10]. Few researchers investigated that wear and friction can be reduced by selecting proper material combinations [8, 11–13]. Researchers observed that friction decreases with an increase in load [14–18] while some investigated its value increases with the increase in load [19, 20]. Wang et all [5] investigated that the sliding speed shows a high influence on the wear than the pressure.

In this pap at dry condition, investigations have been done, parameters such as speed, load, and time on friction and wear behavior of PTFE and its additives. AISI 400C stainless steel disc is used against the material in dry condition. The tests were carried out at load 10, 20, 30 N at a speed of 0.35, 0.66, 0.98 m/s at time intervals.

2 Experimental Details

2.1 Friction and Wear Tests

Friction and wear tests are carried out on Pin on Disc Test rig under dry condition at room temperature. The specimens of pin size are 8 mm diameter and 40 mm length were tested against AISI 400C stainless steel disc. Table 1 shows the chemical composition of the stainless steel disc AISI 400C used in this investigation. Surface roughness of disc was found to be 26.3 μm Ra. Figure 1 represents Pin on Disc wear test rig, which is used in this investigation. The description of the machine is that the

Table 1 AISI 400C chemical composition

% C	% Si	% Mn	% P	% S	% Cr	% Mo	% Ni
0.96	1.4	0.6	0.036	0.029	18	0.69	0.85

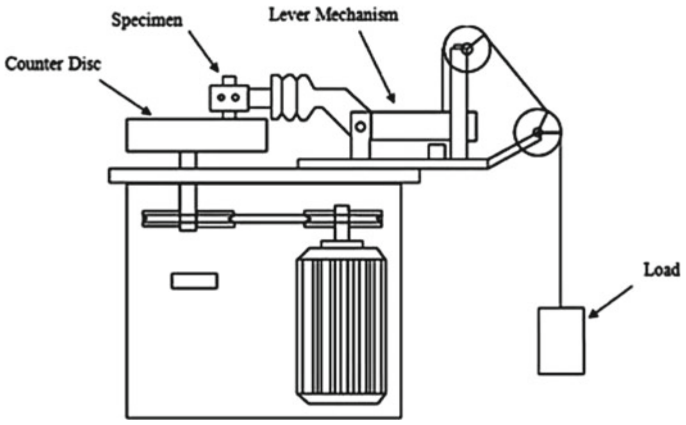

Fig. 1 Schematic diagram of pin on disc test rig

round-shaped specimen can be fitted and pressed into contact of the disc by means of a lever, which is loaded, by lever arm and dead weights. The pin holder carrying the pin is mounted flat, which is free to slide in a direction at right angle to the axis about which the disc rotates. The beam type load cell connected to the indicator measures the tangential force exerted by the disc on the pin. This arrangement avoids any interaction between normal force pressing the pin into contact with the disc and the tangential force arising from friction, thus ensuring accuracy in measurement of friction force. Electric motor through the system of V-belt pulley combination provides necessary rotational speed to the disc. Speed of electric motor can be varied by the use of $1\theta\, i/p$, 3θ o/p frequencies.

Referring to Fig. 1, in which the pin is fixed onto a rotating disc. The load had applied by means of dead weights through the stationary rod against the rotating specimen. The frictional torque is measured with a load cell fastened on the stationary rod. A DC servomotor to provide sliding speeds at different ranges can control the rotating shaft. The load has been varied at different ranges and the temperature of the pin, has been measured with a thermocouple inserted in the specimen holder. The thermocouple has been connected to a meter to record the reading of temperature. The amount of wear has been measured by weight (pan) balance machine/ electronic balance noting the difference of initial and final weight of the specimen. The experiments are carried out at nominal sliding speed at different ranges from 200 to 2000 rpm. The load and pressure have also at different ranges from 1 to 20 kg and 0.2 to 2 N/mm^2. Duration of each test depends upon the rubbing materials as ranges from 15 min to 2 h. Each test has been conducted as long as the thermal condition or the wear rate is reached at steady-state condition. The test has been terminated due to the high rate of wear and rubbing track on the disc is too deep. The material properties and test conditions of the samples are shown in Table 2.

Table 2 The material properties and test conditions of the samples

Materials	Density g/cm^3	Temperature °C	Load *N*	Speed m/s
PTFE	2.10	Room temperature	10	0.35
			20	0.66
			30	0.98
PTFE + 20% GFR	2.42		10	0.35
			20	0.66
			30	0.98
PTFE + 25% Bronze	2.98		10	0.35
			20	0.66
			30	0.98
PTFE + 30% C	2.12		10	0.35
			20	0.66
			30	0.98

GFR–Glass fiber reinforced, C-Carbon

3 Results and Discussions

After the readings and investigation, Table 3 depicts coefficient of friction values for PTFE and its composites at dry conditions. Load applied at 10, 20, 30 N and speed at 0.35, 0.66 and 0.98 m/s respectively. Figure 2 depicts the variation of coefficient of friction of PTFE and composites at 0.35 m/s and at different loads. In Fig. 2, the coefficient of friction decreases with increase in load as the property of polymer is viscoelastic. The variation of coefficient of friction follows the equation $\mu = kN^{(n-1)}$ [20], where μ is the coefficient of friction, N is the load, k and n is constant, its value

Table 3 Coefficient of friction for PTFE and its composites at different speed and load

Materials	Load, *N*	Speed m/s		
		0.35	0.66	0.98
		Coefficient of friction, μ		
PTFE	10	0.34	0.35	0.39
	20	0.2	0.2	0.22
	30	0.15	0.15	0.13
PTFE + 20% GFR	10	0.30	0.29	0.30
	20	0.16	0.16	0.17
	30	0.10	0.10	0.11
PTFE + 25% Bronze	10	0.32	0.32	0.32
	20	0.16	0.175	0.17
	30	0.10	0.11	0.12
PTFE + 30% C	10	0.32	0.34	0.32
	20	0.17	0.18	0.175
	30	0.12	0.11	0.11

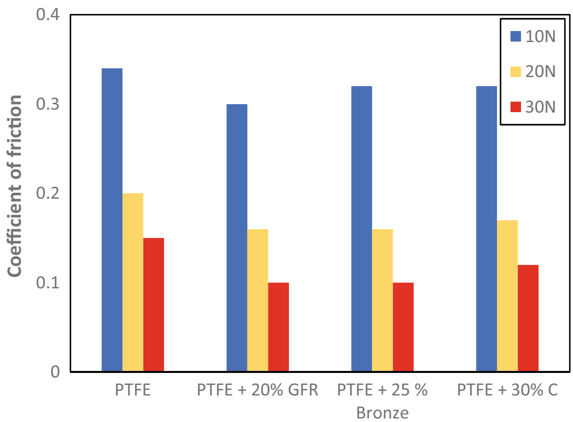

Fig. 2 At 0.35 m/s, coefficient of friction versus PTFE and its composites

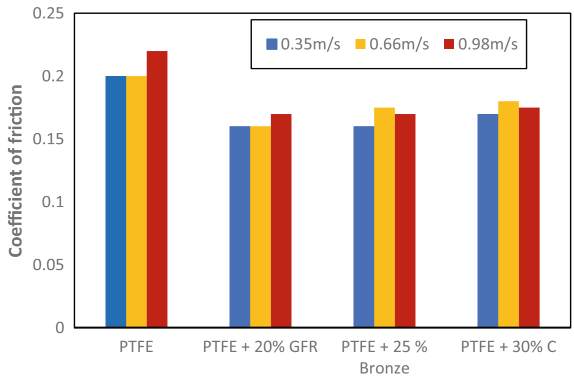

Fig. 3 At load = 20 *N*, variation of coefficient of friction of PTFE and its composites

Table 4 Wear loss for PTFE and its composites at a different speed and load

Materials	Load, *N*	Speed m/s		
		0.35	0.66	0.98
		Wear (mg)		
PTFE	10	16	16	20
	20	20	25	28
	30	24	28	32
PTFE + 20% GFR	10	6	8	9
	20	8.2	9	12
	30	10	13	15
PTFE + 25% Bronze	10	6	10	10
	20	15.6	18.8	15
	30	16	18	18
PTFE + 30% C	10	8	10	12
	20	13	14.8	16
	30	15.4	19	19.3

is 2/3 $<n<$ 1. The above equations show that the friction coefficient decreases with an increase in load. Later after a certain time, as the load increases, the wear and friction will increase due to the critical surface energy of the material polymer. The frictional heat rises the friction temperature at surfaces which comprises leading of molecule chains of polymer. Figure 3 shows the variation at 20 *N* load at different sliding speeds. In Fig. 3, if we compare Fig. 2, decrease in coefficient of friction seen at all speeds. At 20 *N*, decrease in coefficient of friction seen, as that this particular load the chemical and tribological changes are stable and can sustain the pressure but later as we increase load, the plastic flow of material will increase and it will try to stick the surface causing resistance in movement and again heat may rise.

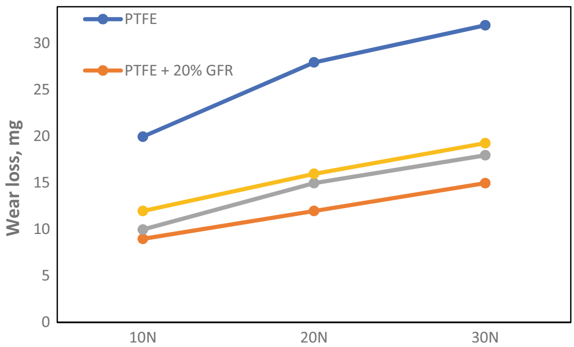

Fig. 4 At 0.98 m/s, variation of wear loss versus load of PTFE and its composites

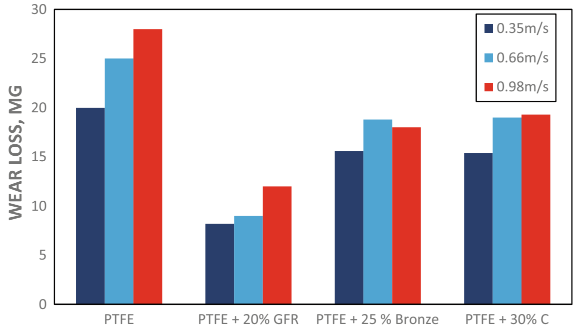

Fig. 5 At 20 N, variation of wear loss versus load of PTFE and its composites

Table 4 shows the wear loss in PTFE and its composites under loads and at different speeds. Figures 4, 5, 6 shows the variation of mass loss at speed and load. From Fig. 4, it understood that speed is not having much influence on mass loss of PTFE and its composites, but Fig. 5 depict that in composite PTFE, wear decreases with an increase in load. In Fig. 5, the material with composites shows resistance to wear and shows its elastic properties, as PTFE.

From Fig. 4, the graph depicts that the highest wear is seen in plain PTFE compare to other PTFE composites. The lowest mass loss was seen at PTFE and 20% GFR, then in bronze and carbon composites, respectively. It is known that the wear loss process involves plastic flow, tribological effects, tribochemical effects, and shearing of material. Due to these effects the changes in wear with load and speed gives rise to wear. With respect to speed there is no maximum significant influence on the wear, if we compare with load on PTFE composite materials. At PTFE and 20% GFR, glass fiber reinforcement is rich in wear resistance material property due to its viscoelastic in nature.

4 Conclusions

From the above study, the following conclusions are drawn.

The coefficient of friction of plain PTFE and its composites decreases when load is applied increases.

Wear also shows a variation with composites of PTFE. Highest wear loss is seen in plain PTFE but PTFE + 20% GFR depicts lowest wear in all. PTFE +30% C gives wear less than bronze. Hence, PTFE with 20% GFR can be considered as very good wear resistance and gives good tribo characteristics between the materials considered in this paper.

Plain PTFE shows maximum wear because of its chemical and mechanical properties, thus PTFE reinforced with glass fiber improves the wear resistance which in turn carries high load capacity in all.

The influence of speed not showing much significant influence on wear, but load depicts a significant effect on wear and shown greater influence on PTFE material and its composites.

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