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Research on Tribological Behaviors of Pure and Glass Fiber Reinforced Nylon 6 Composites against Polymer Disc

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Abstract—*Polymers have replaced by the metals due to excellent strength and stiffness to weight ratio, chemical resistance, corrosion resistance and low processing cost. In this experimental work, the mechanical and tribological properties of pure and glass fiber reinforced (GFR) nylon 6 composites were investigated. Pin specimens of pure and GFR nylon 6 and disc specimens of 30 wt% GFR nylon 6 were fabricated using injection molding machine. Tribological test was carried out under dry condition using pin-on-disc configuration. The coefficient of friction and specific wear rate were study at varying glass fiber content (0, 10, 20 and 30 wt %), different applied load (5, 10, 15 and 20 N), sliding velocity (0.5, 1.0, 1.5 and 2.0 m/s) and constant sliding distance (1000m) under atmospheric conditions of temperature and humidity. To further L16 orthogonal array (OA) was conducted to study with three factors and four levels. Finally, the Worn surface morphology of specimen was study.*

Keywords: *polymer/polymer, mechanical properties, pin-on-disc, dry sliding wear, friction and wear*

1. INTRODUCTION

Polymers have excellent strength and stiffness to weight ratio, chemical resistance and corrosion resistance so polymer/polymer combination selected rather than polymer/steel. However, there has been little information available on the tribological properties of polymer/polymer combinations, because polymers have low thermal conductivity and limited applied load and sliding velocity [1]. Friction, wear, fatigue and corrosion are the major drawbacks found by industries which lead to replacement of parts. Polymer showed low friction coefficient compared to metals because of their low interfacial adhesion energy [2]. Nylon has excellent wear resistance, intrinsic lubrication behavior, tensile and flexural strength owing to carried out van der waal forces and hydrogen bonds in molecular chains of nylon thus used in gears, bearings and sliding machining elements [3]. The usage of polymer in food and chemical industries are essential as it avoids the usage of lubrication. Adhesion and deformation mechanisms have mainly involved in wear and friction of polymer. The deformation mechanism describes about energy dissipation of the contact area of pin and disc specimens [4, 5].

Polymers have low wear resistance, mechanical strength, low thermal conductivity so several reinforcements and filler materials mixed to the polymer to upgrade their tribological, mechanical and thermal behaviour [6]. If applied load increases coefficient of friction decreases but only limited at elastic constant, when plastic deformation starts then coefficient of friction slightly increases due to further increases load [7]. When speed increases in case of PA/POM then coefficient of friction increases due to less thermal conductivity comparison with plastic/steel combination [8]. Polymer/polymer combination under dry condition always produced intermittent motion or stick-slip due to adhesion effect. The rough-rough surface sliding combinations have lower coefficient of friction compare to smooth-smooth surface combination [1]. Generally lubrication is used to reduce the adhesion effect.

The purpose of this study is to evaluate the effect of glass fiber content, applied load and sliding velocity on the coefficient of friction and specific wear rate behaviours of pure and GFR nylon 6 against 30 wt% GFR nylon 6. Worn surface morphology of pin and disc specimens were also discussed.

Table 1: Mechanical properties of various glass fiber (wt %) content nylon 6

Sl. No.	Glass fiber content (Wt %)	Shore hardness (D)	Notched impact strength (J/mm)	Ultimate tensile strength (N/mm2)	% Elong ation	Density (g/mm3)
1	0%	63-65	0.1375	51.208	49.41	0.00113
2	10%	63-67	0.075	53.631	38.22	0.00120
3	20%	73-75	0.125	71.358	19.74	0.00127
4	30%	72-75	0.125	86.014	13.68	0.00137

2. EXPERIMENTAL SETUP

2.1 Tested materials

The selected test polymer materials used in this investigation was pure and GFR nylon 6 in the form of granules. The mechanical properties of pure GFR nylon 6 composites are shown in table 1. Pin specimens with varying glass fiber content of nylon 6 (0, 10, 20 and 30 wt %) and disc specimens 30 wt% GFR nylon 6 for tribological test were produced by injection molding machine (Modern plastic and equipment's, Model-MPE-TLH-01). The upper temperature of injection molding machine is 40°C and lower temperature is maintained at 220°C, 225°C, 230°C and 240°C for 0, 10, 20 and 30 wt % GFR nylon 6 respectively. The size of pin specimen was 31*5*5 mm and disc specimen size was 70 mm diameter and 5 mm thick used for tribological test.

2.2 Friction and wear testing

The tribological test was conducted under dry condition as per ASTM G-99-05 standard on (DUCOM TR-20M-106) pin-on-disc arrangement with pure and GFR nylon 6 pin specimens sliding against 30 wt% GFR nylon 6 disc specimens. The Friction and wear tests were conducted at various glass fiber contents (0, 10, 20 and 30 wt %) applied load (5, 10, 15 and 20 N), sliding velocity (0.5, 1.0, 1.5 and 2.0 m/s) and constant sliding distance(1000m) under atmospheric condition of temperature (23°C) and humidity (67 ±10). Before testing, all the pin specimens were polished using a 600 grade SIC emery paper to ensure full contact with disc and achieved same roughness. . Pin and disc specimen was cleaned using cotton soaked in acetone and dried before the test. The initial weight before experiment and final weight after experiment of specimen were weighted using an electronic digital analytical balance having an accuracy of 0.1 mg.

The specific wear rate K_S (mm^3/Nm) was calculated using the following equations:

Specific wear rate (K_S) = $\frac{m_1-m_2}{\rho \times N \times S}$

Where m_1 and m_2 are mass of the pin specimen before and after experiment (g), ρ represents density of the pin specimen (g/mm^3), N represents applied load (N), and S represents sliding distance (m).

2.3 Experimental design

Taguchi is a powerful tool for optimize the performance through the settings of design parameters and to reduce the fluctuation of system performance. Minitab statistical software can be used to explain the parameter effect. Taguchi method can be used to determine both the optimal result from finite analytical data and the dominant factors involved in the optimization for friction and wear. Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The Taguchi method uses the signal to noise (S/N) ratio. The experimental results are transformed into an S/N ratio. Usually, there are three categories of quality characteristics in the analysis of the S/N ratio, i.e., lower-the-better, higher-the-better, and nominal-the-better. Here Smaller the better characteristic uses:

$$S/N = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right]$$

Where $\bar{y}$ the average of observed data and n is is the number of tests.

The coefficient of friction and specific wear rate was carried out with three control factor such as glass fiber contents, applied loads and sliding velocity each has four levels as shown in table 2. Further, Using Minitab 16 software, ANOVA is performed to determine parameter which has significant effect on the performance.

Table 2: Parameters and their levels

	Parameter	Levels			
		1	2	3	4
A	Glass fiber (wt %)	0	10	20	30
B	Applied load (N)	5	10	15	20
C	Sliding velocity (m/s)	0.5	1.0	1.5	2.0

Table 3: Experimental design using L_{16} orthogonal array

Sl. no.	GFR (Wt %)	Load (N)	Sliding Velocity (m/s)	Coefficient of Friction (μ)	S/N Ratio	Specific Wear Rate (mm3/Nm)	S/N Ratio
1	0	5	0.5	0.374	8.5426	0.0000884	81.0710
2	10	10	0.5	0.292	10.6923	0.00005	86.0206
3	20	15	0.5	0.210	13.5556	0.0000472	86.5212
4	30	20	0.5	0.172	15.2894	0.0000444	67.0523
5	0	10	1.0	0.260	11.7005	0.000168	75.4938
6	10	5	1.0	0.281	11.0259	0.0001	80
7	20	20	1.0	0.179	14.9429	0.000520	65.6799
8	30	15	1.0	0.198	14.0667	0.000138	77.2024
9	0	15	1.5	0.190	14.4249	0.00116	58.7108
10	10	20	1.5	0.185	14.6566	0.00210	53.5556
11	20	5	1.5	0.201	13.9361	0.000125	78.0618
12	30	10	1.5	0.186	14.6097	0.0002	73.9794
13	0	20	2.0	0.201	13.9361	0.00350	49.1186
14	10	15	2.0	0.194	14.2440	0.00300	50.4576

15	20	10	2.0	0.193	14.2889	0.000889	61.0220
16	30	5	2.0	0.210	13.5556	0.000222	73.0729

3. RESULTS AND DISCUSSION

3.1 Effect of glass fiber content, applied load and sliding velocity on coefficient of friction

The variation of coefficient of friction for pure and GFR nylon 6 with the sliding distance under varying glass fiber content, different applied load and constant sliding velocity is shown in fig.[1-4]. The coefficient of friction initially increases and further addition of glass fiber content the then observed coefficient of friction reached steady state. During sliding applied load shared by both glass fiber and nylon, but major part of applied load shared by glass fiber so if glass fiber content increases then coefficient of friction decreased. In case of glass fiber content due to rubbing of glass fiber of faced materials coefficient of friction decreased. Another main cause for variation in coefficient of friction is due to temperature of contact zone. The coefficient of friction decreases with the load increasing. If sliding velocity increased coefficient of friction decreases due to change in temperature of surface of specimen and contact zone. For this specific range of test condition, applied load was more significant on coefficient of friction followed by sliding velocity and glass fiber.

3.2 Effect of glass fiber content, applied load and sliding velocity on specific wear rate

When glass fiber content increases hardness and thermal conductivity increases hence specific wear rate decreases. In case of pure nylon 6, specific wear rate more observed and when glass fiber content increases specific wear rate decreased so in the case of GFR nylon 6 specific wear rate decreased. If applied load increases specific wear rate increases due to increasing area of contact between pin and disc specimen, which produced more heated at contact zone and viscous-elastic property so specific wear rate increases. When sliding velocity increases the specific wear rate also increases due to increases in contact zone of pin specimen. In case of specific wear rate sliding velocity was more significant followed by glass fiber and applied load.

3.3 Taguchi analysis and ANOVA

The aim of this study is to find combination of factors to achieve the minimum coefficient of friction and specific wear rate. Using Minitab 16 software, the results for various combinations of parameters were obtained through orthogonal arrays as shown in tables 3. Also, Figs. 5 and 6 show effect of factor on coefficient of friction and specific wear rate. The S/N ratio responses for coefficient of friction and specific wear rate are shown in tables 4 and 5 respectively. Overall, the results direct to conclusion that combination of factors A4B4C3 and A4B1C1 offer minimum coefficient of friction and specific wear rate. Tables 6 show the results of the ANOVA with the coefficient of friction and table 7 show the results of the ANOVA with specific wear rate wear.

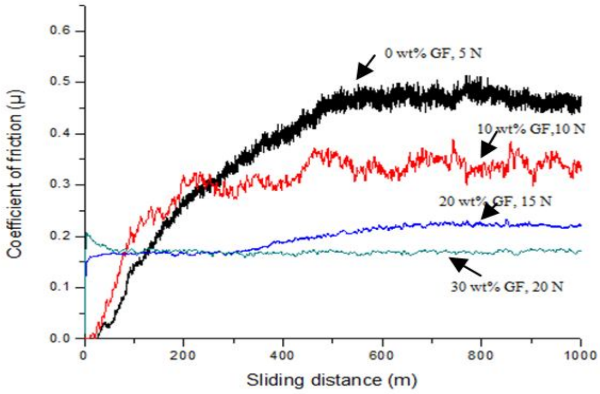

Fig. 1: Relation between sliding distance and coefficient of friction under varying glass fiber content and loads at velocity 0.5 m/s

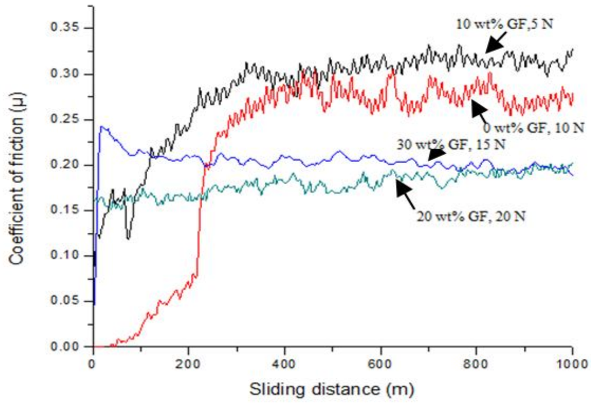

Fig. 2: Relation between sliding distance and coefficient of friction under varying glass fiber content and loads at velocity 1.0 m/s

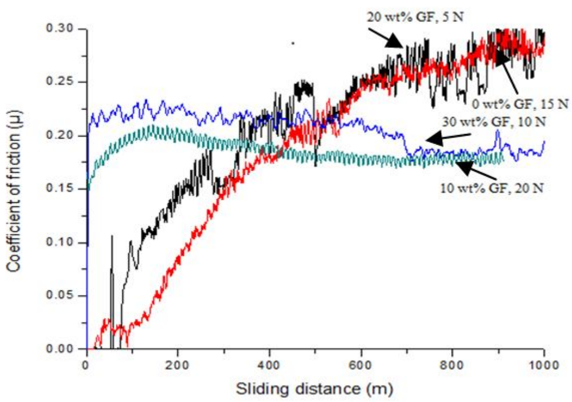

Fig. 3: Relation between sliding distance and coefficient of friction under varying glass fiber content and loads at velocity 1.5 m/s

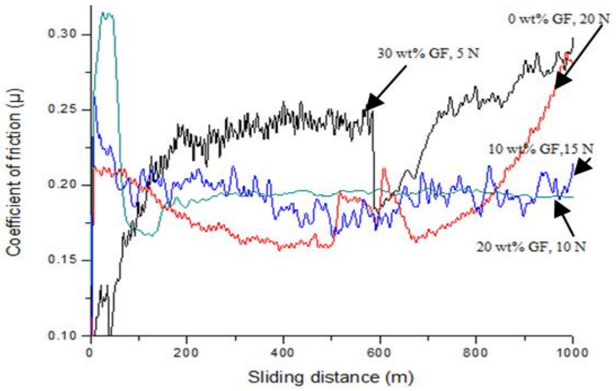

Fig. 4: Relation between sliding distance and coefficient of friction under varying glass fiber content and loads at velocity 2.0 m/s

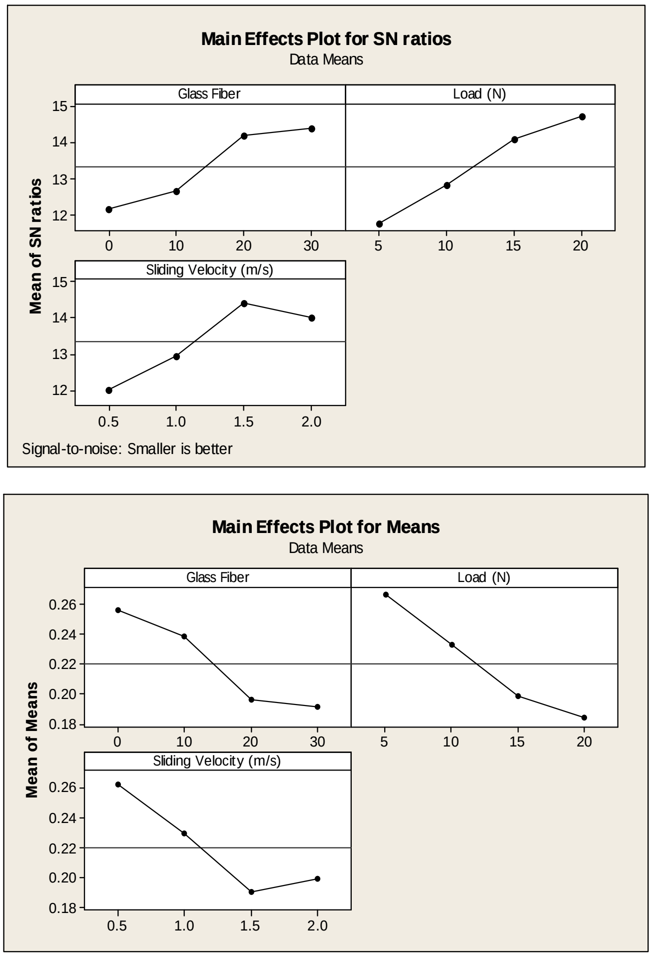

Fig. 5: Effect of control factor on coefficient of friction

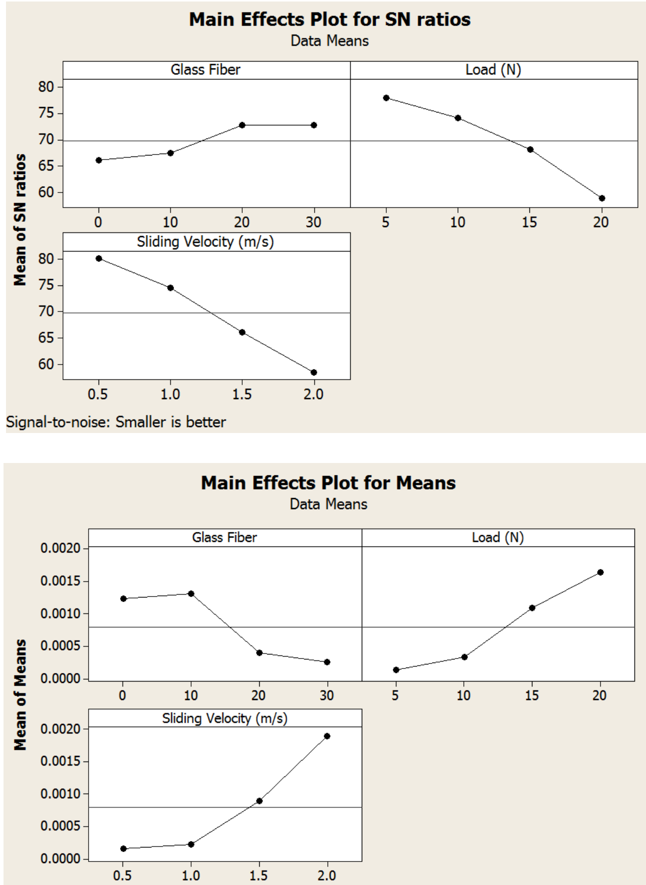

Fig. 6: Effect of control factor on specific wear rate

Table 4: S/N ratio response Table for coefficient of friction

Level	S/N Ratios		
	Glass fiber	Applied load	Sliding velocity
1	12.15	11.77	12.02
2	12.65	12.82	12.93
3	14.18	14.07	14.41
4	14.38	14.71	14.01
Delta	2.23	2.94	2.39
Rank	3	1	2

Table 5: S/N ratio response Table for specific wear rate

Level	S/N Ratios		
	Glass fiber	Applied load	Sliding velocity
1	66.10	78.05	80.17
2	67.51	74.13	74.59
3	72.82	68.22	66.08
4	72.83	58.85	58.42
Delta	6.63	19.20	21.75
Rank	3	2	1

Table 6: Analysis of Variance for Coefficient of friction

Source	DF	Seq SS	Adj MS	F	P	% contribution
Glass fiber	3	0.0121513	0.0040504	7.54	0.018	27.43
Load (N)	3	0.0163453	0.0054484	10.14	0.009	36.90
Sliding velocity (m/s)	3	0.0125767	0.0041922	7.81	0.017	28.39
Residual Error	6	0.0032225	0.0005371			7.27
Total	15	0.0442957				100

Table 7: Analysis of variance for Specific wear rate

Source	DF	Seq SS	Adj MS	F	P	% contribution
Glass fiber	3	0.0000036	0.0000012	7.64	0.018	19.67
Load (N)	3	0.0000058	0.0000019	12.21	0.006	31.69
Sliding velocity (m/s)	3	0.0000078	0.0000026	16.44	0.003	42.62
Residual Error	6	0.0000010	0.0000002			5.46
Total	15	0.0000183				100

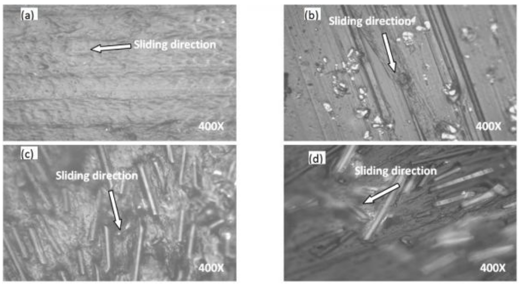

Fig. 7: Microscopy of worn surfaces of the nylon 6 composites under varying glass fiber content and velocity, at a load of 20 N : (a) 0 wt% GF, 2.0 m/s (b) 10 wt% GF, 1.5 m/s (c) 20 wt% GF, 1.0 m/s (d) 30 wt% GF, 0.5 m/s.

3.4 Worn surface morphology

Optical microscopy of the worn surfaces of pure nylon 6 at 2.0 m/s sliding velocity and 20 N applied load shown in fig.[7, a]. In this case show plastic deformation means melt of pin specimen. The reason of this is temperature rise in contact zone because less thermal conductivity so pin specimen softening. Fig. [7, b, c, d] shows the worn surface of nylon 6 under varying glass fiber content there observed sliding direction with rubbed and breakage glass fiber. This is main cause to decrease specific wear rate. The glass fiber observed on the surface of nylon 6 composites; it played a significant role of sharing load.

4. CONCLUSIONS

In this experimental study, effect of glass fiber content, applied load and sliding velocity on coefficient of friction and specific wear rate were observed. On the basis of results, the following major conclusions can be drawn.

- The coefficient of friction and specific wear rate of nylon 6 composites decreases with increases glass fiber content and lowest achieved at 30 wt% glass fiber.
- The coefficient of friction of GFR nylon 6 composites decreased with increasing of applied load and sliding velocity while specific wear rate increases with increasing of applied load and sliding velocity.
- Taguchi analysis gives combination of factor A4B4C3 and A4B1C1 for coefficient of friction and specific wear rate respectively. Applied load was more significant on coefficient of friction followed by sliding velocity and glass fiber while in case of specific wear rate sliding velocity was more significant followed by applied load and glass fiber.
- The worn surface of pure nylon 6 specimen shows plastic deformation means melt of polymer while GFR nylon 6 shows sliding direction with breakage of glass fiber.

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