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Journal of Advanced Research in Materials Science
ISSN (online): 2289-7992 I Vol. 19, No.1. Pages 14-32, 2016

Optimization of Friction and Wear of Nylon 6 and Glass Fiber Reinforced (GFR) Nylon 6 Composites against 30wt. % GFR Nylon 6 Disc

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Abstract – *In food and chemical industry, polymers are widely used as gears and other sliding machining elements due to excellent chemical resistance. So in this paper, the tribological property of Nylon 6 and glass fiber reinforced (GFR) Nylon 6 Composites were investigated. Pin specimen with Nylon 6 and GFR Nylon 6 (10wt. %, 20wt. % & 30wt. %) and disc specimen with 30wt. % GFR Nylon 6 which were fabricated by Injection molding process. The pin and disc specimen were tested for coefficient of friction and specific wear rate under dry sliding condition using a pin-on-disc configuration. The effect of the different applied load, sliding velocity and varying glass fiber content were studied at a constant sliding distance and room temperature. Analysis of variance (ANOVA) was used to find out the significance of process parameters (applied load, sliding velocity and varying glass fiber content) with the coefficient of friction and specific wear rate. Process parameters were optimized by hybrid Taguchi- Grey Relational Analysis (GRA) and Cuckoo Search Algorithm (CSA). The worn surface morphology of pin and disc specimens were also discussed.*

Keywords: Nylon 6 and GFR Nylon 6 Composites, Pin-on-disc, Taguchi's Analysis, Grey Relational Analysis, Cuckoo Search Algorithm

1.0 INTRODUCTION

Friction, wear, fatigue and corrosion are the major drawbacks found by industries which lead to replacement of parts. The polymer materials are replacing traditional materials in many engineering applications due to their attractive properties such as excellent strength, stiffness to weight ratio, chemical resistance, corrosion resistance, impact resistance, fatigue resistance, thermal resistance, wear resistance and low processing cost [1]. The tribological and mechanical properties improved by using glass and carbon fiber in Nylon matrix. The Tribological behaviour is mainly affected by many factors like type, shape, size and reinforcement of the fibers, matrix materials used and the test condition in which the experiment is conducted [2]. Fiber reinforced is often added to polymers to improve tensile, impact, hardness and tribological characteristics [3].

The tensile strength increased while the elongation at break decreased as the PF loading increased. The improvement in tensile strength of composites is due to good adhesion between filler materials and polymer matrix [4].The higher the binder (maleated polypropylene) loading in Kenaf fibre-homopolymer polypropylene composites, the better are the mechanical properties for both tensile and modulus strength, but lower for elongation at break [5]. Study of the tribological properties of polymer matrix composites (PMCs) is drawing interest among the researchers in the last decade. PMCs showed a low friction coefficient compared to metals because of their less interfacial adhesion energy [6]. Nylon has superior wear resistance, intrinsic lubrication behaviour, tensile and flexural strength owing to carried out van der Waal forces and hydrogen bonds in molecular chains of nylon thus used in gears and bearings etc [7]. 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 [8, 9]. In food and chemical industries polymer uses are essential as it avoids the usage of lubrication [10].

Very few researchers carried on tribological properties of polymer-polymer cases compared to polymer-steel because polymer-polymer has low thermal conductivity comparison to polymer-steel and limited load and sliding velocity carrying capacity but if filler material added to polymer then mechanical and tribological properties increased [11]. Tribological properties of PEI + 15% PTFE and PEI + 20% GFR polymer composites rubbing against PPS + 40%SGFR, BMC + 15% LGFR and stainless steel. For the specific range of applied load and sliding speed, explored in this study, the coefficient of friction decreases linearly with the increase in load. The specific wear rate decreases with increase in applied load for polymer-polymer combination but increases or shows no change with increase in applied load for polymer-steel combinations [12]. The specific wear rate was lowest observed in rubbing of PEI + 20% GFR against steel disc and the highest are for rubbing of PEI + 20% GFR against PA 46 + 30% GFR disc followed by PEI + 20% GFR against GP-PEI disc. For the specific range of applied pressure and sliding speed explored in this study, the sliding speed showed stronger effect on the specific wear rate of PEI polymers. Worn surface of polymer showed wear mechanism is a combination of adhesive and abrasive wear [13]. When speed increases in case of PA/POM then coefficient of friction increases due to less thermal conductivity [14]. Wear of materials encountered in industrial situations can be grouped into different categories as shown in Fig. 1[15]. Material properties such as crystallinity, glass transition temperature, mechanical properties, molecular weight, orientation, hardness, and surface energy are factors that have been shown to influence both the friction and wear behavior of polymers under various experimental conditions. On the other, the tribological system itself, more precisely the loading characteristics, the counterpart material, as well as the external conditions including the temperature or the presence of lubricants play a major role in wear mechanism and, subsequently, for the overall wear performance. An overview of the various factors influencing the wear behavior of polymers is shown in Fig. 2 [16].

Multi response optimization problem is converted into a single response optimization problem using grey relational technique. Using this technique, a grey relational grade is obtained and from this value an optimum level of parameters has been find out. Furthermore, using analysis of variance (ANOVA) method, significant contributions of process parameters have been determined [17]. New evolutionary and population based algorithm cuckoo search (CS) is used for optimizing process parameters. This algorithm is based on the breeding behavior of cuckoo birds with the levy flight behavior of some birds [18]. The preliminary experiments show the promising results of this approach in the field of Process parameters optimized by hybrid Taguchi- Grey Relational Analysis and Cuckoo Search Algorithm [19].

This paper reports, the tribological properties of pure and varying glass fiber reinforced nylon-6 pin against 30wt. % GFR Nylon-6 disc. In this study specific wear rate and coefficient of friction is measured with varying glass fiber contents, applied loads and sliding velocities. The worn out surface of pin and disc specimens were investigated by using scanning electron microscope and optical microscope.

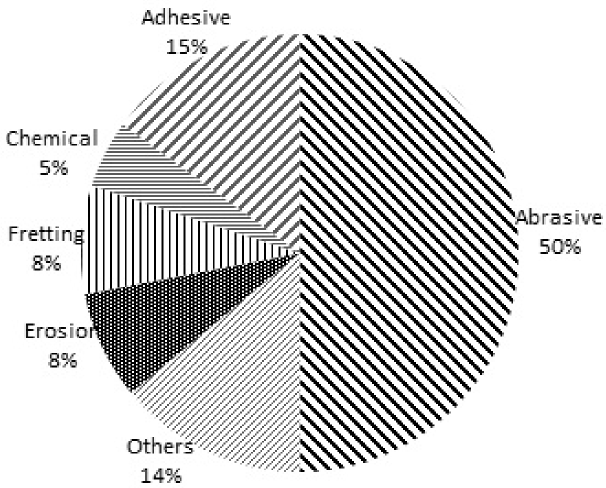

Figure 1: Type of wear in Industry (Approximate percentage involved)

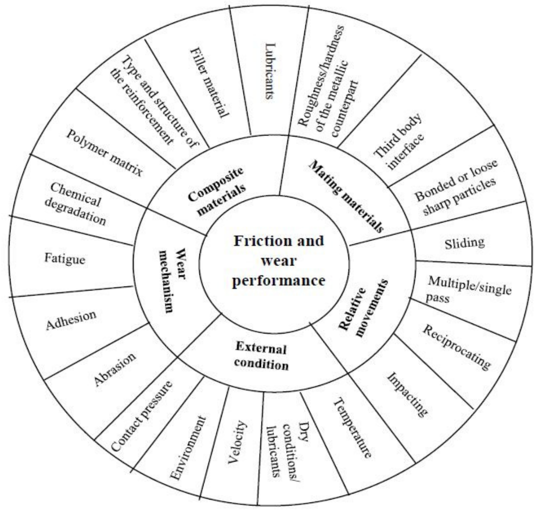

Figure 2: Factors determining the wear and friction behavior of polymers

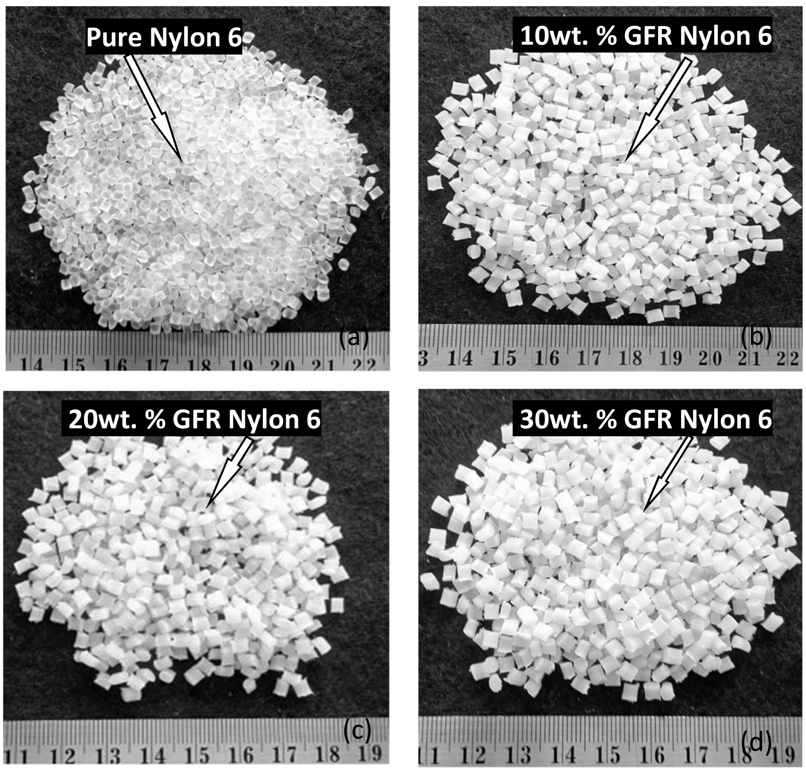

Fig. 3: (a) Pure Nylon 6, (b-d) 10, 20 and 30wt. % Glass Fiber reinforced Nylon 6 respectively (Granules form)

Journal of Advanced Research in Materials Science
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2.0 EXPERIMENTAL PROCEDURE

2.1 Material and specimen details

The selected raw materials used in this investigation were Nylon 6 and glass filled Nylon 6 (10wt. %, 20wt. % & 30wt. %) in the form of granules as shown in Fig. 3(a-d).These granules are heated in an oven for two hours at 80°C to remove moisture. Pin specimens were made by Nylon 6 and (10, 20 and 30 wt. %) GFR Nylon 6 and disc specimens were made by 30wt. % GFR nylon 6 fabricated for mechanical and tribological test using injection molding machine (Modern plastic and equipment's, Model-MPE-TLH-01). The temperature is maintained at 220°C, 225°C, 230°C and 240°C for Nylon 6 and 10, 20 and 30wt. % GFR Nylon 6 respectively. The tensile properties of the Nylon 6 and GFR Nylon 6 composites was evaluated using ASTM D638-14, shore D hardness was evaluated using ASTM D2240-05 and notched impact strength was evaluated using ASTM D 256-10. The dimensions of Nylon 6 and GFR Nylon-6 composites pin specimen was 31 mm length and 6 mm diameter as per ASTM G99-05. Density of Nylon 6 was observed 0.00113 g/mm^3, 10wt. % GFR Nylon 6 was 0.00120 g/mm^3, 20wt. % GFR Nylon 6 was 0.00127 g/mm^3 and 30wt. % GFR Nylon 6 was 0.00135 g/mm^3, Disc specimen 30wt. % glass fiber reinforced Nylon 6 was 70 mm diameter and 5 mm thickness.

2.2 Friction and wear analysis

Tribological test were carried out under dry sliding condition as per ASTM G-99-05 standard on DUCOM TR-20M-106 pin-on-disc tribo tester with pure and GFR nylon 6 pin specimens sliding against 30wt. % GFR Nylon 6 disc specimens. Fig. 4 shows the schematic diagram of pin-on-disc setup.

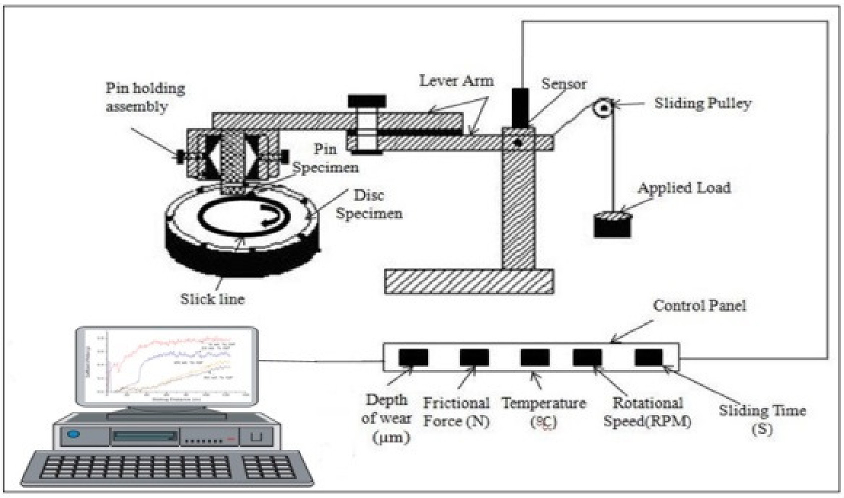

Figure 4: Schematic diagram of pin-on-disc setup

The disc which was used have surface roughness (Ra=0.6±0.05 μm) achieved by polished using several emery papers. Track diameter of pin specimen on disc was 40 mm. Friction and wear tests were done at various glass fiber contents (0, 10, 20 and 30wt. %), applied loads (5, 10, 15 and 20 N), sliding velocity (0.5, 1.0, 1.5, 2.0 m/s), constant sliding distance (1000 m) under dry condition at input temperature (23°C) and humidity (67 ±10 %). Pin specimens were pre-worn using a 600 grade SiC emery paper for full contact between pin and disc surface. Pin and disc specimen was cleaned using acetone and thoroughly dried. The initial weight before

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ISSN (online): 2289-7992 l Vol. 19, No.1. Pages 14-32, 2016

experiment and final weight after experiment of specimen were weighted using an electronic digital analytical balance having an accuracy of 0.0001 g. The specific wear rate K_S (mm^3/Nm) was quantified from Eq.1.

$$\text{Specific wear rate } (K_S) = \frac{m_1 - m_2}{\rho \times N \times S} \tag{1}$$

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

2.3 Taguchi's design of experiment

Taguchi is a powerful tool for optimize the performance through the settings of design parameters. The experimental results are transformed into signal to noise (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 as shown in Eq. 2.

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

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

2.4 Grey relational analysis

Grey relational analysis is using for convert Multi response optimization problem into single response optimization problem. In this process normalize the experimental data in the range between 0 and 1. The normalized value of coefficient of friction and specific wear rate values corresponding to smaller the better equality criterion which can be expressed in this work. Therefore, the normalized S/N ratio x_{ij} for the íth performance characteristic in the jth experiments can be expressed in Eq. 3.

$$x_{ij} = \frac{\max_j \eta_{ij} - \eta_{ij}}{\max_j \eta_{ij} - \min_j \eta_{ij}} \tag{3}$$

Where x_{ij} represent the sequence after data processing, η_{ij} the original sequence of S/N ratio (where i=1, 2, 3…m, j= 1, 2, 3…n), max η_{ij} the largest value of η_{ij}, and min η_{ij} the smallest value of η_{ij}.

Basically, the larger normalized S/N ratio corresponds to the better performance and the best normalized S/N ratio is equal to unity. The grey relational coefficient is calculated to express the relationship between the ideal and actual normalized S/N ratio. The grey relational coefficient ξ_{ij} for the íth performance characteristic in the jth experiment can be expressed in Eq. 4.

$$\xi_{ij} = \frac{\min_i \min_j \left| x_i^0 - x_{ij} \right| - \xi \max_i \max_j \left| x_i^0 - x_{ij} \right|}{\left| x_i^0 - x_{ij} \right| + \xi \max_i \max_j \left| x_i^0 - x_{ij} \right|} \tag{4}$$

Where x_i^0 represent the ideal normalized S/N ratio for the íth performance characteristic and ζ the distinguishing coefficient which is in the range $0 \leq \zeta \leq 1$. After averaging the grey relational coefficients, the grey relational grade γ_i can be obtained, as shown in Eq. 5.

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i (k) \tag{5}$$

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Where *n* represent the number of process responses. A higher value of the grey relational grade means that the corresponding process parameter is closer to the optimal one. Using Minitab 16 software, ANOVA is performed to determine parameter which has significant effect on the performance.

2.5 Cuckoo search algorithm

Cuckoo search (CS) is an evolutionary and population based approach that mimics the breeding behavior of cuckoo birds. It was first proposed by xin-she yang and suash dev based on the breeding behavior of cuckoo birds. The preliminary experiments show the promising results of this approach in the field of search and optimization. The idealized rules of cuckoo search can be stated as follows:

1) Each cuckoo lays an egg on the randomly chosen nest.
2) The number of nests (agents) and eggs (individuals) in each nest are fixed.
3) Nest with high quality of eggs (Elite members) are passed on to the next generation.
4) If the host bird discovers an alien egg based on the external characteristics of an egg such as colour and spots, then host bird either throws the alien egg away or builds an entirely new nest at the new location.

For feature selection, the host nest n is defined as an agent containing multiple eggs (or individuals) called population. Each egg is represented as a binary string, with a 1 for an inclusion of feature (or attribute) and a 0 for exclusion of feature. Step 4, is implemented by maintaining the index of worst nest and replacing it with better individuals. Levy flights, is a random walk and named after a French mathematician Paul Levy, in which steps are defined in terms of steps- length having a probability distribution that is heavy tailed. The direction of the steps in levy flights can be isotropic or random. Various studies demonstrated the flight behavior of many insects and animals based on levy flights. In the past decade, these behaviors have been applied in optimization and optimal search and found to yield promising results.

In this algorithm, each egg in a nest represents a solution, and each cuckoo can lay one egg (means one solution) When generating new solutions $x^{t+1}$for, say cuckoo i, a L´evy flight is performed as shown in Eq. 6.

$$x_i^{t+1} = x_i^t + \alpha \oplus Levy(\lambda) \quad (6)$$

Where α >0 is the step size which should be related to the scales of the problem of interest. In most cases, we can use α = (0, 1). The product ⊕ means entry-wise multiplications. Levy flights essentially provide a random walk while their random steps are drawn from a Levy distribution for large steps as shown in Eq. 7.

$$\text{Levy} \sim u = t^{-\lambda}, (1 < \lambda \leq 3) \quad (7)$$

This has an infinite variance with an infinite mean.

3.0 RESULTS AND DISCUSSION

The mechanical characterization includes evaluation of tensile strength, impact strength and hardness of the composite as shown in Table 1. The tribological characterization are evaluated against various counterface (320 grit size SiC abrasive paper, AISI D2 steel disc and 30wt. % glass fiber reinforced Nylon 6).

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

Sl. No.	Glass fiber content (wt. %)	Shore D hardness ASTM D2240-05	Notched impact strength (J/mm) ASTM D256-10	Ultimate tensile strength (MPa) ASTM D638-14
1	0%	63-65	0.1375	51.208
2	10%	63-67	0.075	53.631
3	20%	72-74	0.125	71.358
4	30%	73-75	0.125	86.014

Tribological tests are carried out under dry condition for Nylon 6 and GFR Nylon 6 composites against 30wt. % glass fiber Nylon 6 counterface. The operating conditions used for the experimentation is listed in Table 2. The experiments were conducted using L_{16} orthogonal array details of which are shown in Table 3.

Table 2: Control factors and their levels

Factors symbol	Control factors	Levels			
		1	2	3	4
A	Glass fiber (wt. %)	0	10	20	30
B	Load (N)	5	10	15	20
C	Sliding velocity(m/s)	0.5	1.0	1.5	2.0

Table 3: Experimental results for coefficient of friction and specific wear rate at 1000 m sliding distance

Exp. Run	Glass fiber (wt. %)	Load (N)	Sliding velocity (m/s)	Coefficient of friction (μ)	Weight loss (g)	Specific wear rate (mm³/Nm)
1	0	5	0.5	0.374	0.0005	0.0000884
2	0	10	1.0	0.260	0.0019	0.0001680
3	0	15	1.5	0.190	0.0339	0.0011600
4	0	20	2.0	0.201	0.0791	0.0035000
5	10	5	1.0	0.281	0.0006	0.0001000
6	10	10	0.5	0.292	0.0006	0.0000500
7	10	15	2.0	0.194	0.0540	0.0030000
8	10	20	1.5	0.185	0.0504	0.0021000
9	20	5	1.5	0.201	0.0008	0.0001250
10	20	10	2.0	0.193	0.0113	0.0008890
11	20	15	0.5	0.210	0.0009	0.0000472
12	20	20	1.0	0.179	0.0132	0.0005200
13	30	5	2.0	0.210	0.0015	0.0002220
14	30	10	1.5	0.186	0.0027	0.0002000
15	30	15	1.0	0.198	0.0028	0.0001380
16	30	20	0.5	0.172	0.0012	0.0004440

3.1 Effect of Glass Fiber Content, Load and Sliding Velocity on coefficient of friction

The variation of coefficient of friction for Nylon 6 and GFR Nylon 6 with the sliding distance under varying glass fiber content irrespective of loads is shown in Fig. 5. The coefficient of friction initially increases and further addition of glass fiber content the then observed coefficient of friction reached steady state. During sliding load shared by both glass fiber and Nylon, but major part of load shared by glass fiber as shown in Fig. 6 so if glass fiber content increases then coefficient of friction decreased upto 20 wt. %. The coefficient of friction was highest in the case of pure Nylon 6 and on further addition of glass fiber the coefficient of friction decreased but in case of 30 wt. % again increased due to same contact material as shown in Fig. 7.

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, load was more significant on coefficient of friction followed by sliding velocity and glass fiber.

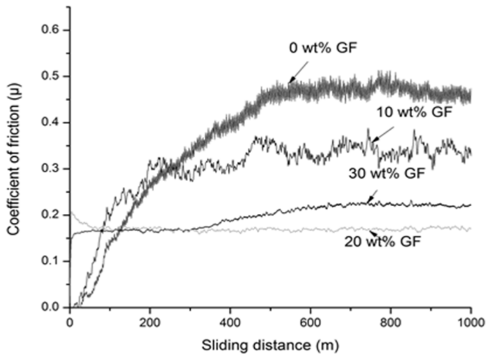

Fig. 5: Relation between sliding distance and coefficient of friction irrespective of load

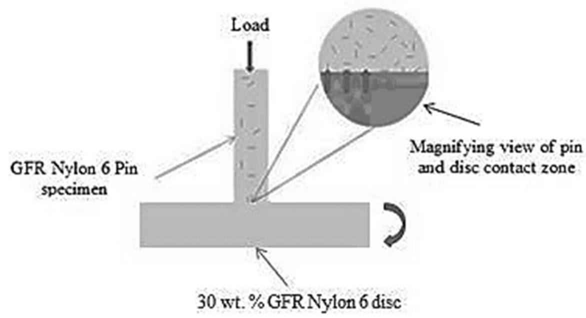

Fig. 6: Schematic representation of load sharing between glass fibres and Nylon 6

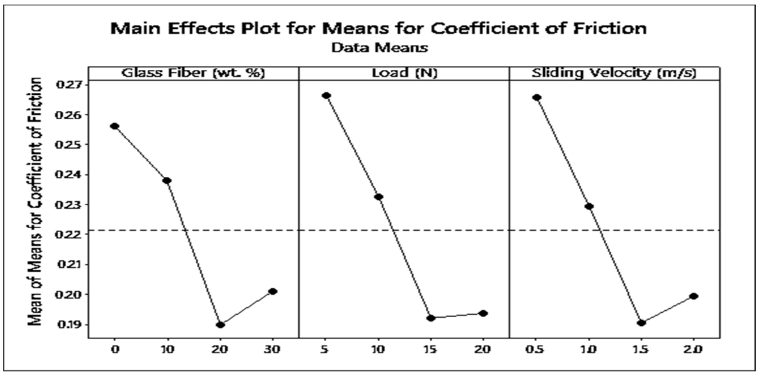

Fig. 7: Effect of control factor on coefficient of friction (μ) for mean value

3.2 Effect of Glass Fiber Content, Load and Sliding Velocity on Specific Wear Rate

When glass fiber content increases hardness and strength 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 is shown in Fig. 8.

Journal of Advanced Research in Materials Science
ISSN (online): 2289-7992 I Vol. 19, No.1. Pages 14-32, 2016

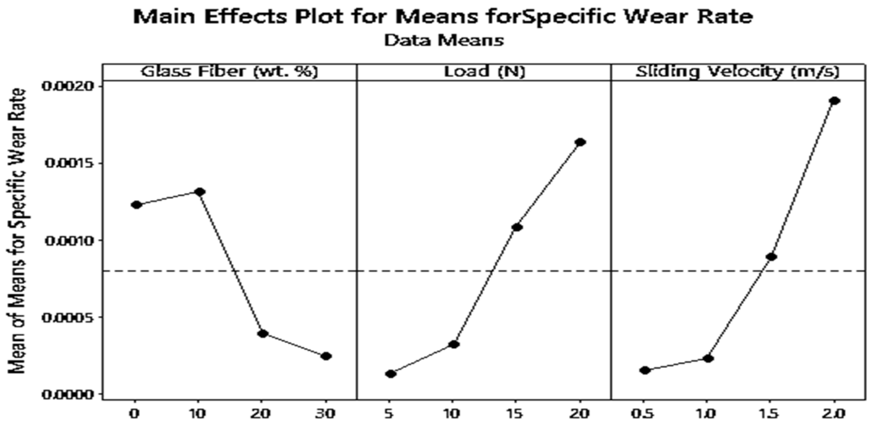

Figure 8: Effect of control factor on Specific wear rate (mm^3/Nm) for mean value

If 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 is shown in Fig. 8. In case of specific wear rate sliding velocity was more significant followed by glass fiber and load.

3.3 Taguchi analysis and analysis of variance

The aim of tribological study is to find combination of factors to achieve the minimum coefficient of friction and specific wear rate. Combination of factors 20wt. % glass fiber content, 15 N load and 1.5 m/s sliding velocity offer minimum coefficient of friction as shown in Fig. 9. Combination of factors 30wt. % glass fiber content, 5 N load and 0.5 m/s sliding velocity offer minimum specific wear rate as shown in Fig. 10.

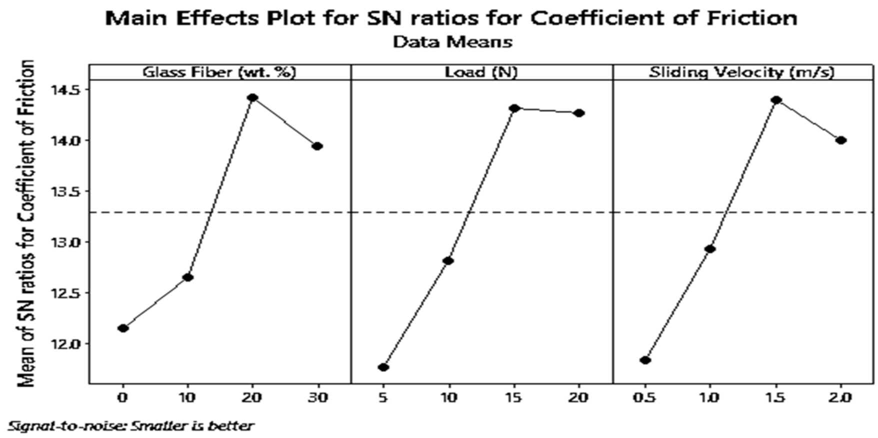

Figure 9: Effect of control factor on coefficient of friction (μ) for S/N ratio

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ISSN (online): 2289-7992 I Vol. 19, No.1. Pages 14-32, 2016

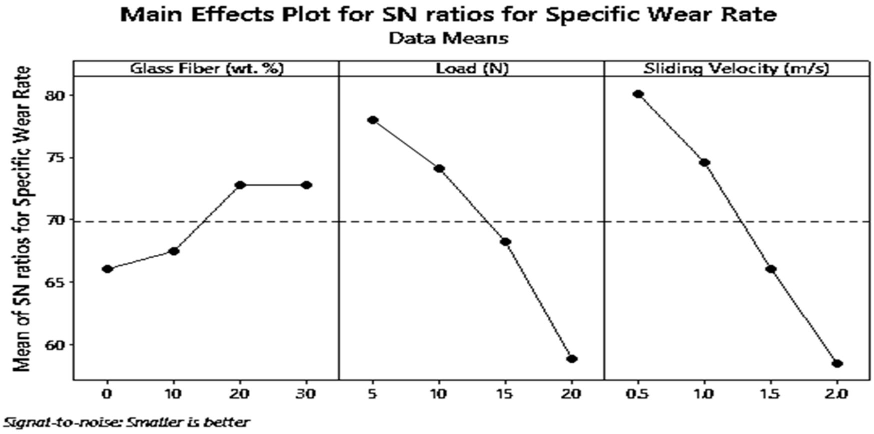

Figure 10: Effect of control factor on Specific wear rate (mm^3/Nm) for S/N ratio

The S/N ratio responses for coefficient of friction are shown in Table 4 and mean values responses for coefficient of friction are shown in Table 5 respectively. The S/N ratio responses for specific wear rate are shown in Table 6 and mean values responses for specific wear rate are shown in Table 7 respectively. Table 8 show the results of the ANOVA with the coefficient of friction and Table 9 show the results of the ANOVA with specific wear rate wear. On the basis of ANOVA for minimum coefficient of friction observed that glass fiber content 26.87 %, sliding velocity 32.20 % and load 35.09 % exerts a significant influence. For specific wear rate the glass fiber content 22.23 % has the most contribution on the output followed by sliding velocity 44.45 % and load 33.34 %.

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

Level	S/N Ratios		
	Glass fiber	Load	Sliding velocity
1	12.15	11.77	11.84
2	12.65	12.82	12.93
3	14.43	14.32	14.41
4	13.95	14.27	14.01
Delta	2.28	2.56	2.57
Rank	3	2	1

Table 5: Mean response Table for coefficient of friction

Level	Mean		
	Glass fiber	Load	Sliding velocity
1	0.2563	0.2665	0.2657
2	0.2380	0.2328	0.2295
3	0.1900	0.1922	0.1905
4	0.2010	0.1937	0.1995
Delta	0.0663	0.0743	0.0752
Rank	3	2	1

Table 6: S/N ratio response Table for Specific wear rate

Level	S/N Ratios		
	Glass Fiber	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	6.73	19.20	21.75
Rank	3	2	1

Table 7: Mean response Table for Specific wear rate

Level	Mean		
	Glass Fiber	Load	Sliding velocity
1	0.0012	0.0001	0.0001
2	0.0013	0.0003	0.0002
3	0.0003	0.0010	0.0008
4	0.0002	0.0016	0.0019
Delta	0.0010	0.0015	0.0017
Rank	3	2	1

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Table 8: Analysis of Variance for Coefficient of friction

Source	DOF	Adj. SS	Adj. MS	F- cal.	P- value	% contribution
Glass fiber (wt. %)	3	0.011569	0.003856	9.21	0.012	26.87
Load (N)	3	0.015108	0.005036	12.03	0.006	35.09
Sliding Velocity (m/s)	3	0.013868	0.004623	11.05	0.007	32.20
Residual Error	6	0.002511	0.000418	-	-	5.84
Total	15	0.043055	-	-	-	100

Table 9: Analysis of Variance for Specific wear rate

Source	DOF	Adj. SS	Adj. MS	F – cal.	P - value	% contribution
Glass Fiber (wt. %)	3	0.000004	0.000001	7.64	0.018	22.23
Load (N)	3	0.000006	0.000002	12.21	0.006	33.34
Sliding Velocity (m/s)	3	0.000008	0.000003	16.44	0.003	44.45
Residual Error	6	0.000001	0.000000	-	-	-
Total	15	0.000018	-	-	-	-

3.4 Grey relational analysis of coefficient of friction and specific wear rate

Experiments were conducted according to L_{16} orthogonal arrays and the experimental results for coefficient of friction and specific wear rate are shown in Table 10.

Table 10: Grey Relational analysis for Tribological Properties of Nylon 6 and GFR Nylon 6 Composites

Exp. Run	Glass Fiber (wt. %)	Load (N)	Sliding Velocity (m/s)	Coefficient of Friction (μ)	Specific Wear Rate (mm^3/Nm)	Normalized Response		Grey Relational coefficient		Grey Relational Grade	Rank
						Coefficient of Friction	Specific Wear Rate	Coefficient of Friction	Specific Wear Rate		
1	0	5	0.5	0.374	0.0000884	0	0.9880	0.3333	0.9766	0.6550	14
2	0	10	1.0	0.260	0.0001680	0.5846	0.9650	0.5462	0.9346	0.7404	10
3	0	15	1.5	0.190	0.0011600	0.943	0.6777	0.8986	0.6080	0.7533	9
4	0	20	2.0	0.201	0.0035000	0.8871	0	0.8159	0.3333	0.5746	16
5	10	5	1.0	0.281	0.0001000	0.4769	0.9847	0.4887	0.9703	0.7295	12
6	10	10	0.5	0.292	0.0000500	0.4205	0.9991	0.4631	0.9983	0.7307	11
7	10	15	2.0	0.194	0.0030000	0.9230	0.144	0.8666	0.3689	0.6178	15
8	10	20	1.5	0.185	0.0021000	0.9692	0.4054	0.9420	0.4568	0.6994	13
9	20	5	1.5	0.201	0.0001250	0.8871	0.9774	0.8159	0.9568	0.8863	5
10	20	10	2.0	0.193	0.0008890	0.9282	0.7561	0.8744	0.6722	0.7733	8
11	**20**	**15**	**0.5**	**0.187**	**0.0000472**	**0.9589**	**1**	**0.9241**	**1**	**0.9620**	**1**
12	20	20	1.0	0.179	0.0005200	1	0.8630	1	0.7850	0.8925	4
13	30	5	2.0	0.210	0.0002220	0.8410	0.9493	0.7587	0.9080	0.8334	6
14	30	10	1.5	0.186	0.0002000	0.9641	0.9557	0.9330	0.9186	0.9258	2
15	30	15	1.0	0.198	0.0001380	0.9025	0.9737	0.8369	0.9500	0.8934	3
16	30	20	0.5	0.210	0.0004440	0.8410	0.8850	0.7587	0.8131	0.7859	7

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Multi response optimization problem is converted into single response optimization problem using grey relational technique. The normalized values are shown in Table 10 and are calculated according to lower the better criteria. Ideally, the larger normalized value in both the responses is the best normalized value and are equal to unity. Further grey relational coefficient is calculated from the normalized value. In this study, equal weight age is given to the response so the distinguishing coefficient ζ is taken as 0.5. Grey relational grade is obtained by average of grey relational coefficients. By using grey relational grade multi response characteristics converted in single response. Highest grey relational grade shows optimum level of factor. Using Minitab 17 Software, larger the better criterion shown in Fig 11. The mean response for grey relational grade is shown in Tables 11.

The highest average grey relational grade for each factor will be optimum parameter. It is shown from the Fig. 11 that the optimum designs parameter combination for minimum coefficient of friction and specific wear rate.

Table 11: Response table of mean for Grey relational grade

Levels	Glass fiber (wt. %)	Load (N)	Sliding velocity (m/s)
1	0.6808	0.7761	0.7835
2	0.6944	0.7926	0.8140
3	0.8786	0.8067	0.8163
4	0.8597	0.7381	0.6998
Delta	0.1977	0.0686	0.1165
Rank	1	3	2

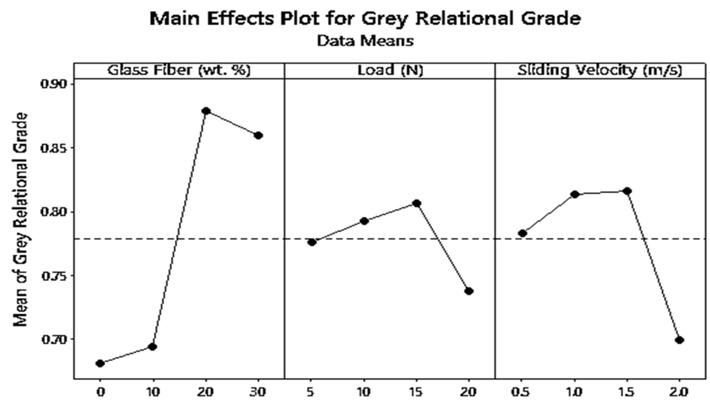

Figure 11: Effect of control factors with their levels for Grey Relational grade

3.5 Analysis of variance of Grey Relational Grade

ANOVA analysis was done for Grey relational grades and the results are presented in Table 12. The glass fiber content (49.74%) has the most contribution on the output followed by sliding velocity (29.76%) and load (10.28%). It is observed that the glass fiber has the highest contribution on friction and wear.

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Table 12: Analysis of variance of Grey Relational Grade

Factors	DOF	Adj. SS	Adj. MS	F-cal.	P-value	Contribution (%)
Glass fiber (wt. %)	3	0.190997	0.063666	9.74	0.010	49.74
Load (N)	3	0.039477	0.013159	2.01	0.214	10.28
Sliding velocity (m/s)	3	0.114283	0.038094	5.83	0.033	29.76
Residual Error	6	0.039231	0.006538	-	-	10.22
Total	15	0.383988	-	-	-	100

3.6 Confirmation tests for Taguchi-grey analysis

Once the optimal level of the design parameters has been determined, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters. The predicted value of grey relational grade is 0.9866 which is in good agreement with the experimental value 0.9730 ($A_3B_3C_3$) as shown in Table 13.

Table 13: Measured responses of confirmation experiment for Taguchi-Grey

	Optimal Parameters		Error (%)
	Prediction	Experiment	
Parameter levels	$A_3B_3C_3$	$A_3B_3C_3$	
Coefficient of Friction (μ)		0.185	
Specific Wear Rate (mm^3/Nm)		0.0000451	
Grey relational grade	0.9866	0.9730	1.4

3.7 Implementation of Cuckoo search algorithm

The objective function is to minimize the Grey Relational Grade, which is given as,

Regression Equation of Grey Relational Grade (GRG) as shown in Eq. 8.

$$GRG = 0.9469 + 0.00721 \text{ Glass Fiber} - 0.00200 \text{ Load} - 0.0497 \text{ sliding velocity} \quad (8)$$

Lower and upper limits of the parametric constraints are $0 \leq$ Glass fiber (wt. %) ≤ 30, $0.5 \leq$ Sliding velocity (m/s) ≤ 2.0, $5 \leq$ Load (N) ≤ 20. The cuckoo search parameter values are, Assume the number of nests n=25, discover rate=0.25, number of iteration=100.

These parametric variable constraints bounds and values are given into the cuckoo search algorithm code written in Matlab R2009a and the output of algorithm is analyzed. Fig. 12 shows the objective obtained during minimization of the GRG for all iterations. It is observed that initially the value of the objective function is at a higher value and as the iteration progresses, the objective function values converge quickly and it gets settled for the further iterations. The best solution obtained is objective function value of 0.5010 for glass fiber content of 20wt. %, sliding velocity 1.5 m/s and load of 10 N for lower coefficient of friction and specific wear rate as shown in Fig. 13-15.

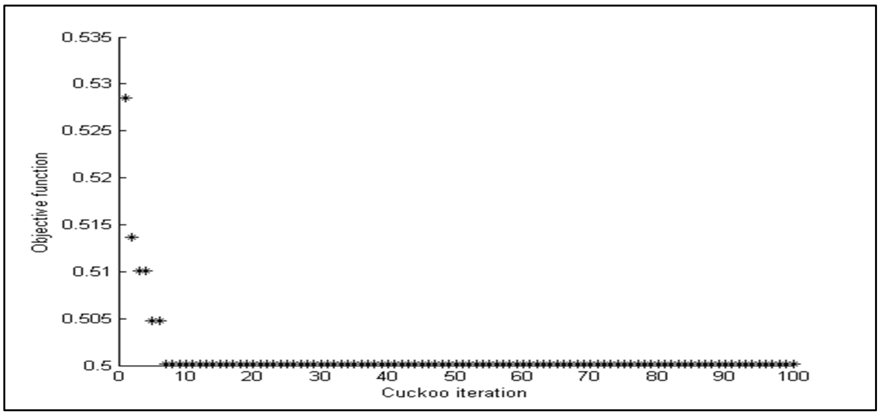

Figure 12: Variation of objective function with iterations

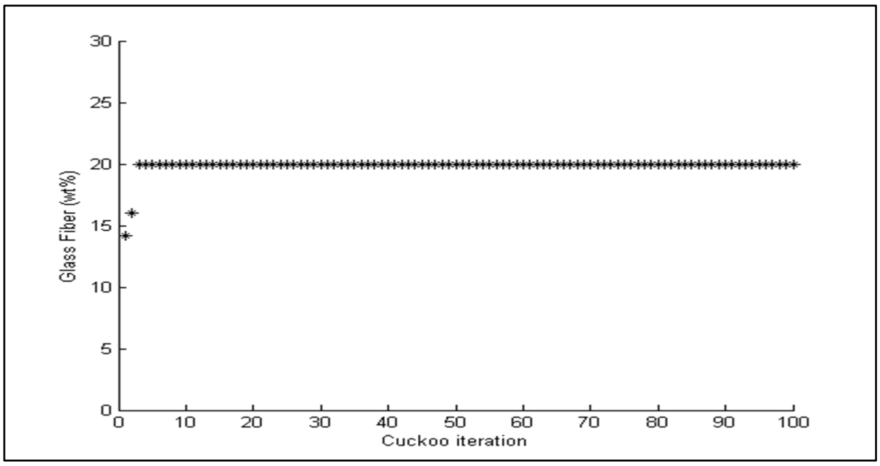

Figure 13: Variation of Glass Fiber with iterations

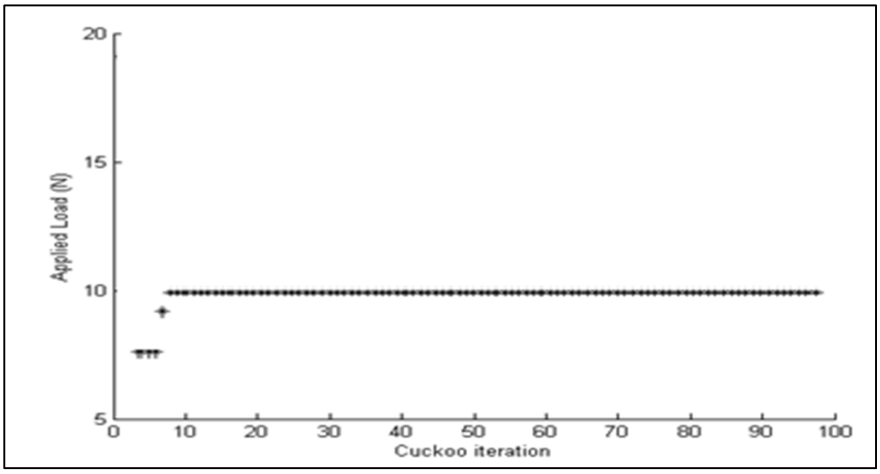

Figure 14: Variation of Load with iterations

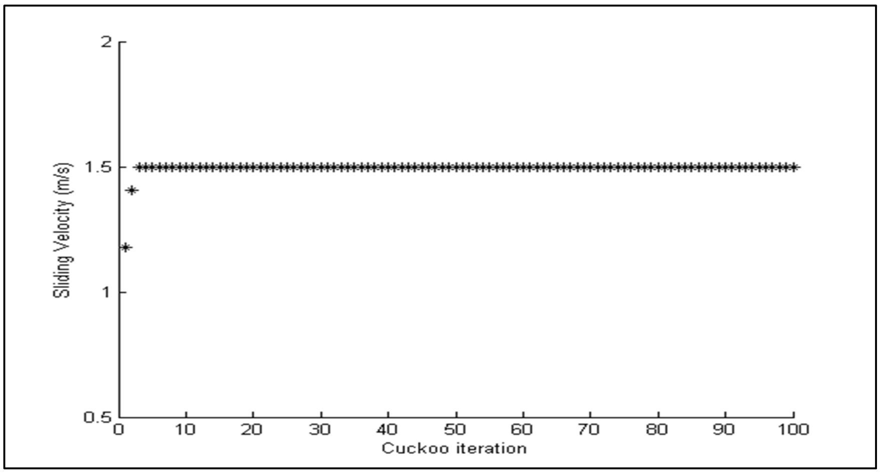

Figure 15: Variation of Sliding Velocity with iterations

3.8 Confirmation tests for Cuckoo search algorithm

With the identified optimal machining parameters of glass fiber content of 20wt. %, sliding velocity of 1.5 m/s and load of 10 N, a confirmation experiment is conducted with the same experimental setup and the measured output responses obtained are given in Table 14.

Table 14: Measured responses of confirmation experiment for cuckoo search

	Optimal Parameters	
	Prediction	Experiment
Parameter levels	$A_3B_2C_3$	$A_3B_2C_3$
Coefficient of Friction (μ)		0.182
Specific Wear Rate (mm^3/Nm)		0.0000410
Grey relational grade (GRG)	0.996	0.981
Objective function = 1/(1+GRG)	0.501	0.504

3.9 Worn surface morphology

Abrasive wear occurs when material is removed from one surface by another harder material, leaving soft particles of debris on hard surface. Fig. 16-17 shows mechanism of two body abrasive wear phenomena and adhesive wear phenomena respectively. The worn surface morphologies of Nylon 6 and GFR Nylon 6 composites were examined using scanning electron microscope and optical microscope. SEM micrography of the worn surfaces of pure Nylon 6 shown in Figs.18(a, b). 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. 19(a, b) shows the worn surface of Nylon 6 under 30wt. % 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. At 5 N load worn surface showing wrinkle with sliding direction shown in Fig. 20a while at 20 N adhesion, abrasion and melting with sliding direction was observed shown in Fig. 20b. This is due to temperature rises of contact zone. Fig. 21 shows transfer layer on 30wt. % GFR Nylon 6 disc.

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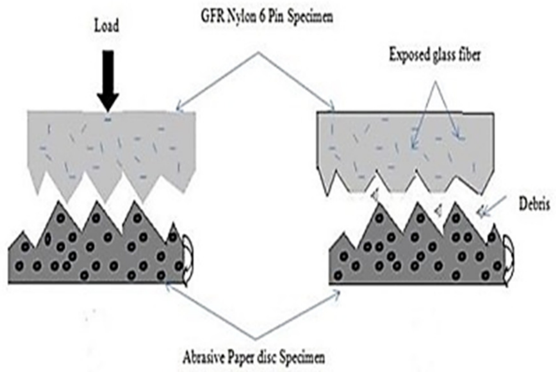

Figure 16: Schematic representations of the abrasion wear mechanism

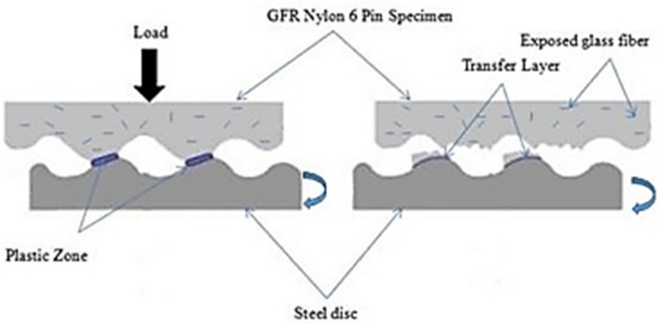

Figure 17: Schematic representation of the adhesive wear mechanism

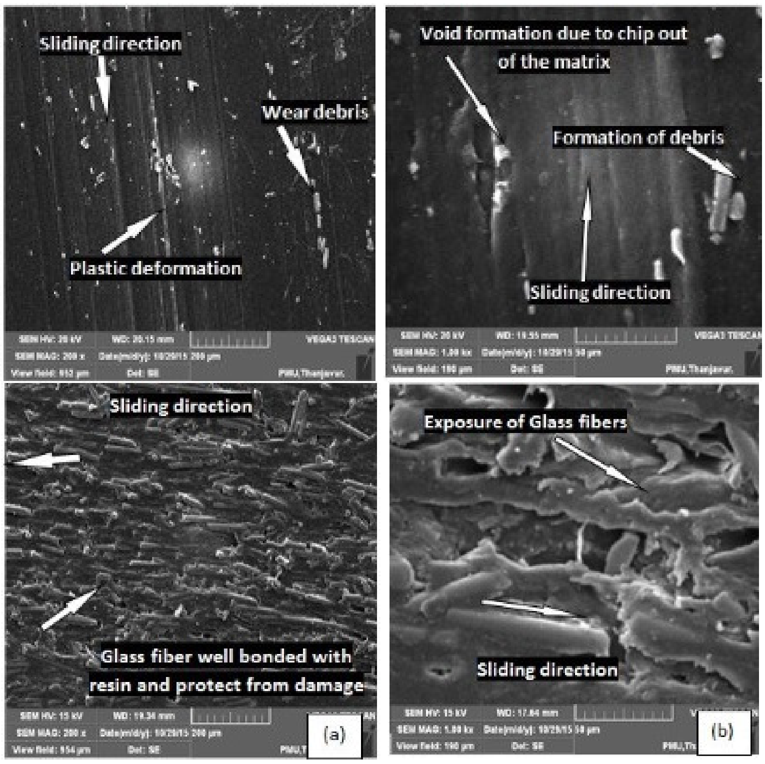

Fig. 19: SEM micrograph of worn surface at 20 N load of 30 wt. % GFR Nylon 6 (a) lower magnification and (b) higher magnification

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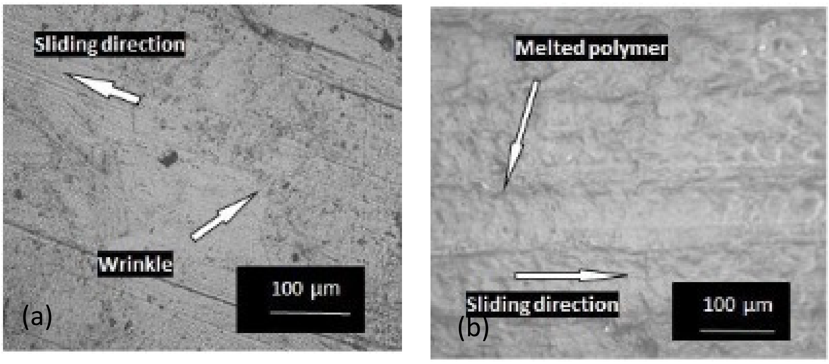

Figure 20: Microscopy of worn surfaces of the Nylon 6: (a) at a load of 5 N (b) at load of 20 N

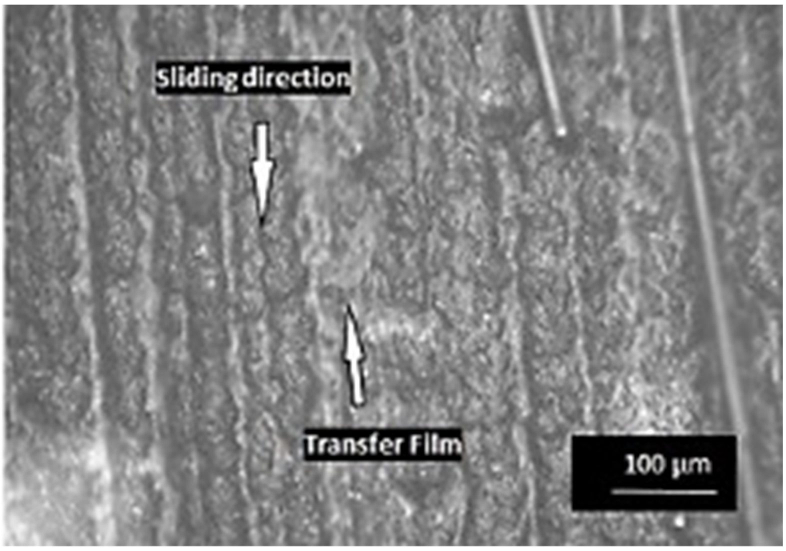

Figure 21: Transfer film formed on the 30wt. % GFR Nylon 6 disc surface

4.0 CONCLUSION

In this experimental study, Tribological properties of Nylon 6 and GFR Nylon 6 composites were tested under varying loads, glass fiber contents and sliding velocity, based on the results in presented above; the following major conclusions are drawn:

- The coefficient of friction and specific wear rate of Nylon 6 and GFR Nylon 6 composites decreases with increases glass fiber content and lowest achieved at 20 wt. % glass fiber and 30 wt. % glass fiber respectively.
- 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.
- On the basis of Taguchi, Combination of factors 20wt. % glass fiber content, 15 N applied load and 1.5 m/s sliding velocity offer minimum coefficient of friction and offer minimum coefficient of friction 30wt. % glass fiber content, 5 N applied load and 0.5 m/s sliding velocity offer minimum specific wear rate respectively.
- On the basis of ANOVA for minimum coefficient of friction observed that glass fiber content 26.87 %, sliding velocity 32.20 % and applied load 35.09 % exerts a significant

influence. For specific wear rate the glass fiber content 22.23 % has the most contribution on the output followed by sliding velocity 44.45 % and load 33.34 %.

- On the basis of Taguchi, grey relational analysis observed that the optimum combination of parameters are 20wt. % glass fiber content, 15 N applied load and 1.5 m/s sliding velocity.
- On the basis of ANOVA of grey relational grade observed that glass fiber content 49.74 %, sliding velocity 29.76 % and applied load 10.28 % exerts a significant influence on multiple response.
- Cuckoo search shows 20wt. % glass fiber content, 10 N applied load and 1.5 m/s sliding velocity combination of factor gives the best solution.
- The worn surface of pure Nylon 6 specimen shows plastic deformation means melt of polymer while GFR Nylon 6 shows sliding direction with exposed glass fiber.

REFERENCES

[1] Panneerselvam, K., S. Aravindan, and A. Noorul Haq. "Study on resistance welding of glass fiber reinforced thermoplastic composites." Materials & Design 41 (2012): 453-459.

[2] Kukureka, S. N., C. J. Hooke, M. Rao, P. Liao, and Y. K. Chen. "The effect of fibre reinforcement on the friction and wear of polyamide 66 under dry rolling–sliding contact." Tribology International 32, no. 2 (1999): 107-116.

[3] Basavaraj, E., and Siddaramaiah. "Sliding Wear Behavior of Nanoclay Filled Polypropylene/Ultra High Molecular Weight Polyethylene/Carbon Short Fiber Nanocomposites." Journal of Macromolecular Science, Part A: Pure and Applied Chemistry 47, no. 6 (2010): 558-563.

[4] Ho, S. H., A. G. Supri, and H. Ismail. "Enhancing Interfacial Adhesion of Potash Feldspar with Silane (Si-69) Coupling Agent on Properties of Ethylene Vinyl Acetate (EVA)/Natural Rubber (NR)/Potash Feldspar Composites."

[5] Ali, Md, Mohd Amran, Hazwani Hilmi, Mohd Sani, Siti Salmah, Zulkeflee Abdullah, Effendi Mohamad, and Pay Jun Liew. "Evaluation of Mechanical Performance of Homopolymer Polypropylene/Kenaf Fibre/Binder using Full Factorial Method." Advanced Research in Materials Science 1, no. 1 (2014): 7-13.

[6] Srinath, G., and R. Gnanamoorthy. "Effect of short fibre reinforcement on the friction and wear behaviour of nylon 66." Applied Composite Materials 12, no. 6 (2005): 369-383.

[7] Xing, Y., G. Zhang, K. Ma, T. Chen, and X. Zhao. "Study on the friction and wear behaviors of modified PA66 composites." Polymer-Plastics Technology and Engineering 48, no. 6 (2009): 633-638.

[8] Unal, H., A. Mimaroglu, and T. Arda. "Friction and wear performance of some thermoplastic polymers and polymer composites against unsaturated polyester." Applied surface science 252, no. 23 (2006): 8139-8146.

[9] Kumar, Sudhir, and K. Panneerselvam. "Research on Tribological Behaviors of Pure and Glass Fiber Reinforced Nylon 6 Composites against Polymer Disc."

[10] Myshkin, N. K., M. I. Petrokovets, and A. V. Kovalev. "Tribology of polymers: adhesion, friction, wear, and mass-transfer." Tribology International 38, no. 11 (2006): 910-921.

[11] Jia, Bin-Bin, Tong-Sheng Li, Xu-Jun Liu, and Pei-Hong Cong. "Tribological behaviors of several polymer–polymer sliding combinations under dry friction and oil-lubricated conditions." Wear 262, no. 11 (2007): 1353-1359.

[12] Mimaroglu, A., and H. Unal. "Sliding Performance of PEI Composites Under Dry Atmospheric Conditions." (2013).

[13] Mimaroglu, A., H. Unal, and T. Arda. "Friction and wear performance of pure and glass fibre reinforced poly-ether-imide on polymer and steel counterface materials." Wear 262, no. 11 (2007): 1407-1413.

[14] Pogačnik, A., and M. Kalin. "Parameters influencing the running-in and long-term tribological behaviour of polyamide (PA) against polyacetal (POM) and steel." Wear 290 (2012): 140-148.

[15] Eyre, T. S. "Wear characteristics of metals." Tribology International 9, no. 5 (1976): 203-212.

[16] Friedrich, Klaus, and Alois K. Schlarb. Tribology of polymeric nanocomposites: friction and wear of bulk materials and coatings. Vol. 55. Elsevier, 2011.

[17] Kuo, Yiyo, Taho Yang, and Guan-Wei Huang. "The use of a grey-based Taguchi method for optimizing multi-response simulation problems." Engineering Optimization 40, no. 6 (2008): 517-528.

[18] Yang, Xin-She, and Suash Deb. "Engineering optimisation by cuckoo search." International Journal of Mathematical Modelling and Numerical Optimisation 1, no. 4 (2010): 330-343.

[19] Senthilkumar, N., T. Tamizharasan, and V. Anandakrishnan. "An hybrid Taguchi-grey relational technique and cuckoo search algorithm for multi-criteria optimization in hard turning of AISI D3 steel." Journal of Advanced Engineering Research 1, no. 1 (2014): 16-31.