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ScienceDirect
Procedia Technology 25 (2016) 1129 – 1136
Procedia Technology

Global Colloquium in Recent Advancement and Effectual Researches in Engineering, Science and Technology (RAEREST 2016)

Two-body Abrasive Wear Behavior of Nylon 6 and Glass Fiber Reinforced (GFR) Nylon 6 Composite

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Abstract

Polymer composite materials are replacing traditional metal materials in many engineering applications due to their attractive properties such as excellent strength and stiffness to weight ratio, chemical resistance, corrosion resistance and low processing cost. In this experimental study, the mechanical and abrasive wear behavior of the Nylon 6 and GFR Nylon 6 composites was determined. Nylon 6 and GFR Nylon 6 composites specimen was fabricated for mechanical and wear test using injection molding machine. Wear test was carried out under dry condition against 320 grit size abrasive paper using pin-on-disc configuration. The effect of varying glass fiber contents (0, 10, 20 and 30wt. %), applied loads (5, 10, 15 and 20 N), sliding distance 500 m were studied at 23^{0}C temperature under humid atmospheric condition. The results showed that as the glass fiber content increases, specific wear rate decreases and it is lowest achieved at 30wt. % of glass fiber. The analysis shows that the abrasive weight loss increases with increases of load. Microstructural analysis of worn surface was investigated by using scanning electron microscope and optical microscope.

Peer-review under responsibility of the organizing committee of RAEREST 2016

Keywords: Nylon 6 and GFR Nylon 6 Composites; Mechanical property; Two-body abrasive wear; Scanning electron microscopy

Nomenclature

GFR	Glass Fibre Reinforced
SiC	Silicon Carbide
wt. %	Weight Percentage

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Peer-review under responsibility of the organizing committee of RAEREST 2016
doi:10.1016/j.protcy.2016.08.228

1. Introduction

Fiber reinforced polymeric composites (FRPC) are most rapidly emerging materials due to their excellent strength and stiffness to weight ratio and low processing cost. FRPC are widely used for a variety of engineering applications which requires resistance to abrasion. The common applications in highly abrasive system are conveyor aids vanes, seals, bushes, conveyor belt, wind blades, gears for pumps handling industrial fluids, agricultural, mining and earth moving equipment's [1]. Abrasive wear is so significant among all forms of wear that is contributes approximately 50 % of total wear [2] and approximately 63 % of the total cost due to wear [3]. Abrasive wear occurs when material is removed from one surface by another harder material, leaving hard particles of debris between the two surfaces. Abrasive wear occur under two conditions, namely two body abrasion and three body abrasion [4]. In fact the abrasion involves the tearing away of small piece of material therefore the tensile strength and hardness are important factors in determining the wear characteristics of FRPC. 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 [5-6].

Nylon has superior wear resistance, intrinsic lubrication behavior and good tensile strength owing to hydrogen bond and van der waals force present in molecular chains of nylon [7]. B. N. Ramesh and B. Suresh studied abrasive wear properties of polymer composites against SiC abrasive paper. They observed that filler loading have more significant influence on abrasive wear performance following by grit of abrasive paper, filler type, abrading distance and normal load. [8]. Wear resistance improved with increase glass fiber content. By using glass and carbon fiber in nylon matrix, both tribological and mechanical properties were improved. However, the behavior 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 [9]. Unal et al. [10] studied the abrasion wear behaviors of 18 types of polymer, observed that Low Density Polyethylene have lowest wear rate at abrasion against rough mild steel compare to abrasive with coarse corundum paper and also found that wear rate decreases when sliding distance and grit grade number increases. Specific wear rate of polymer composites decreased with increasing glass fiber content [11, 12]. Liu et al. [13] revealed that the hardness and ploughing resistance increased with addition of filler material. If short carbon fiber added with PA/PP then significant influence observed under varied abrading distance and applied load [14]. The friction coefficient and specific wear rate of polytetrafluoroethylene decreased with increasing PA 6 reinforcement and best obtained with the composites containing 30 vol. % of PA 6 [15].

The objective of this paper is to study the abrasive wear behaviors of glass fiber reinforced Nylon 6 composites against 320 grit size abrasive paper. Wear mechanism of worn out surface was investigated by using scanning electron microscope and optical microscope.

2. Experimental procedure

2.1. Material and specimen details

The raw materials used for injection moulding are commercially available Nylon 6 and GFR Nylon 6 in the form of granules. GFR Nylon 6 composites (0, 10, 20, and 30 wt. %) pin specimens were fabricated by injection moulding machine. The temperature of injection molding machine was maintained at 220°C, 225°C, 230°C and 240°C for 0, 10, 20 and 30wt. % GFR Nylon 6 composites respectively. The Tensile strength and Shore D hardness of the GFR Nylon 6 composite specimen was evaluated using ASTM D638-14 and ASTM D2240-05 respectively. The dimensions of GFR Nylon-6 composites pin specimen was 31 mm length and 6 mm diameter as per ASTM G99-05.

2.2. Friction and wear test details

Dry sliding wear test were carried out under multi-pass condition as per ASTM G-99-05 standard on DUCOM TR-20M-106 pin-on-disc tribo tester. Fig. 1 shows the schematic diagram of pin-on-disc setup. Abrasive paper of 320 grit size was pasted on a rotating (AISI D2 steel disc) using double-sided adhesive tape. 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 30 wt. %), applied loads (5, 10, 15 and 20 N) at constant sliding velocity (0.5 m/s) and sliding distance (500 m) under dry condition at input temperature (23^0C) 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 specimen was cleaned using acetone and thoroughly dried. The tribological test arrangement consists of a rotating spindle at the center to which a disc was fixed using a countersunk bolt. The frictional force was continuously measured using with load cell. A pivoted lever arm was provided on which there was provision for holding the pin on one end and load on other end. The track diameter could be fixed with the help of horizontal scale provided on the surface of equipment's. The rotational speed and time were set using the control unit and then the lever arm holding the pin was rest on the disc. The required load was applied on other side of the lever arm. Initially, the depth of wear and frictional force were set to zero. The initial weight before experiment and final weight after experiment of specimen were weighted using an electronic digital analytical balance having an accuracy of 0.0001 g. The specific wear rate K_S (mm^3/Nm) was quantified from the following equations:

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

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).

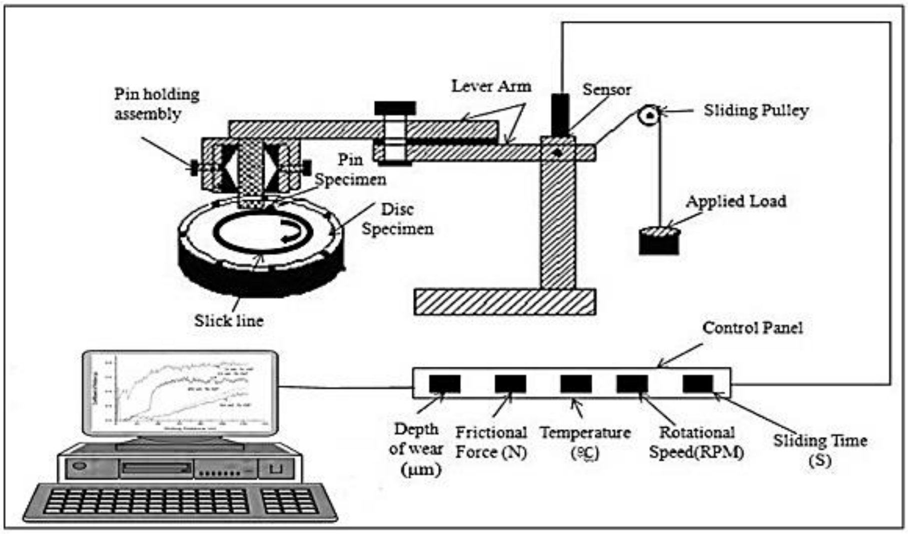
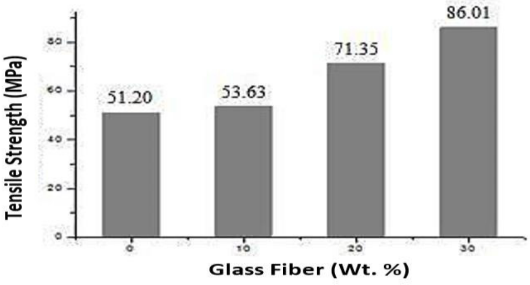


Fig. 1. Schematic diagram of pin-on-disc setup

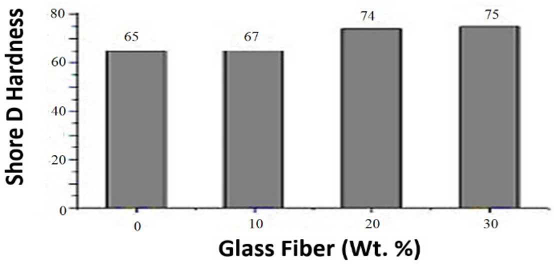
3. Experimental results and discussion

3.1. Results of mechanical characterisation of GFR Nylon 6 composite

The tensile strength of Nylon 6 and GFR Nylon 6 composites increases with increase in glass fiber wt. % as shown in Fig. 2(a). The improved tensile strength of composites is due to excellent dispersion of reinforcement and good adhesion between the matrix and reinforcement which transfer the tensile load. Hardness is considered as one of the most important factors that affect the wear property of materials. The Shore D hardness of Nylon 6 and GFR Nylon 6 composites increases with increase in glass fiber wt. % as shown in Fig. 2(b).The improved shore D hardness of Nylon 6 GFR composites is due to brittle nature of glass fiber, good dispersion of the reinforcement and good adhesion between the matrix and reinforcement.



(a)



(b)

Fig. 2. Mechanical properties of GFR Nylon 6 (a) Tensile strength (b) Shore D hardness

3.2. *Abrasive wear studies*

Two body multi pass abrasive wear tests are carried out for Nylon 6 and GFR Nylon 6 composites. The operating conditions used for the experimentation is listed in Table 1. The experimental results for abrasive wear rate are shown in Table 2.

Table 1 Test parameters for Abrasive wear test

Sl. NO.	Test Parameters	Units	values
1	Load	N	5, 10, 15 and 20
2	Glass Fiber	(Wt. %)	0, 10, 20 and 30
3	Sliding velocity	m/s	0.5 (interval of time is 4.16 minutes)
4	Sliding distance	m	500
5	Temperature	ºC	23

Table 2 Experimental results for abrasive wear test

Ex. No.	Glass Fiber (wt. %)	Load (N)	Weight loss (g)	Specific wear rate (mm^3/Nm)
1	0	5	0.207	0.0732
2	0	10	0.269	0.0476
3	0	15	0.286	0.0337
4	0	20	0.293	0.0259
5	10	5	0.123	0.041
6	10	10	0.143	0.0238
7	10	15	0.226	0.0251
8	10	20	0.239	0.0199
9	20	5	0.103	0.0324
10	20	10	0.126	0.0198
11	20	15	0.182	0.0191
12	20	20	0.197	0.0155
13	30	5	0.069	0.020
14	30	10	0.093	0.013
15	30	15	0.128	0.012
16	30	20	0.147	0.010

3.2.1. *Effect of Normal load on weight loss of Nylon 6 and GFR Nylon 6 composites*

The variation of weight loss with respect to load at varying glass fiber content is shown in Fig. 3. Weight loss was observed lower at low load (5 N). This is due to lower penetration and less number of abrasive particles was in contact with the rubbing surface. The weight loss of Nylon 6 and GFR Nylon 6 composites increases with increases in applied load. This is due to increases depth of penetration of the SiC grit on the material surface which created more grooves. When applied load increases weight loss also increases due to more amount of heat produced at contact zone. Due to the heat produced at the contact zone, polymer surface layer gets plastically deformed which results in debonding.

3.2.2. *Effect of glass fiber on weight loss of Nylon 6 and GFR Nylon 6 composites*

The variation of weight loss with respect varying glass fiber content to varying load at is shown in Fig. 4. The weight loss of Nylon 6 composites decreases with increase in glass fiber contents. This is due to improvement of hardness and strength.

3.2.3. *Effect of sliding distance on specific wear rate of Nylon 6 and GFR Nylon 6 composites*

The variation of specific wear rate with respect to different sliding distance at varying glass fiber content is shown in Figs. [5 - 8].The specific wear rate of nylon 6 composites decreases with an increase in sliding distance. This is due to the space between the abrasive is filled by the debris, which reduces the depth of penetration.

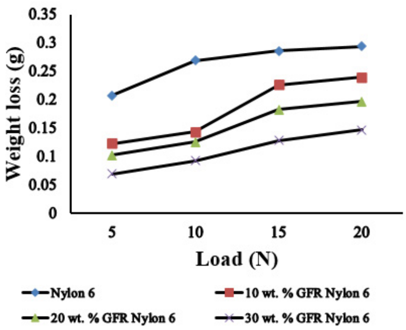


Fig. 3. Abrasive weight loss as a function of load at sliding distance 500 m

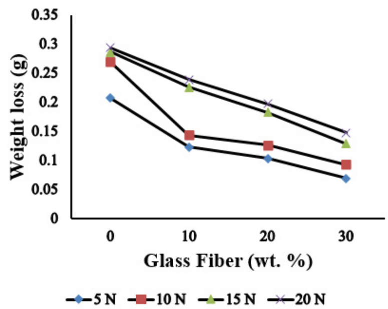


Fig. 4. Abrasive weight loss as a function of glass fiber content at sliding distance 500 m

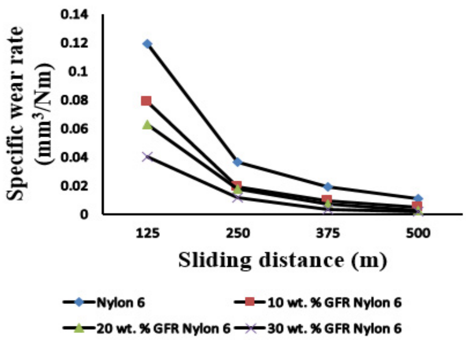


Fig. 5. Specific wear rate as a function of sliding distance at 5 N

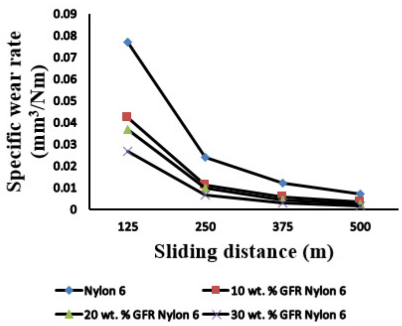


Fig. 6. Specific wear rate as a function of sliding distance at 10 N

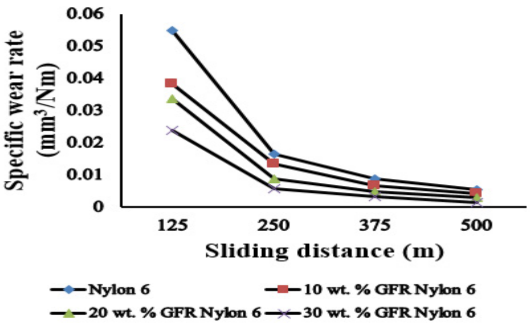


Fig. 7. Specific wear rate as a function of sliding distance at 15 N

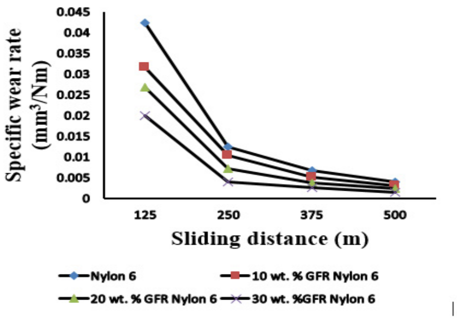


Fig. 8. Specific wear rate as a function of sliding distance at 20 N

3.2.4. Wear mechanism

Abrasive wear occurs when material is removed from one surface by another harder material, leaving soft particles of debris on hard surface. Fig. 9 shows schematic of two body abrasive wear phenomena. The worn surface morphologies of Nylon 6 and GFR Nylon 6 composites were examined using scanning electron microscope and optical microscope. At 500 m sliding distance more debris were observed to be deposited on the abrasive paper which promotes the clogging of wear debris in the crevices and covers the abrasive particles and eventually causes the paper to reach a steady state after repeated number of passes and thereby minimizing the effect of abrasiveness as shown in Fig. 15 while at 125 m sliding distance very less clogging of wear debris in the crevices observed as shown in Fig. 16. The worn surface of pure Nylon 6 specimens is shown in Fig. 11. Plastic deformation, micro-cracking, micro-cutting and wear debris are showing with furrows. This happened because thermal softening effect means generation of high frictional heat at contact zone under high load. When glass fiber wt. % increased then plastic deformation and wear debris properties decreased as shown in Fig. 12. This happened due to applied load sharing between fibers and the matrix as shown in Fig.10. The worn surface of 30wt. % glass fiber Nylon 6 composites under 20 N load shown less indication of groves, plastic deformation and wear debris as shown in Fig. 12. Fig. 13 and 14 shows the SEM micrographs of nylon composites with 30wt. % GFR subjected to load of 5 N and 20 N respectively. The surface morphology shows that at 20 N load exhibits surface damage is caused by fracture of the fiber and damage of the matrix which results in debonding of the fibers while at 5 N load surface is very less damaged.

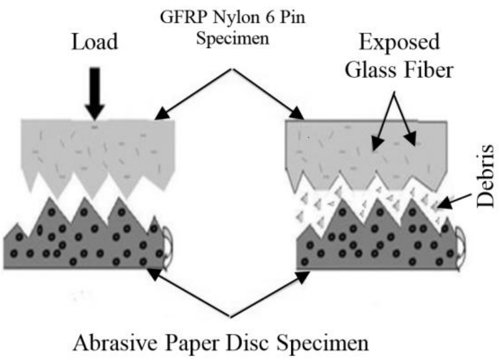


Fig. 9. Mechanism of Two Body Abrasion wear

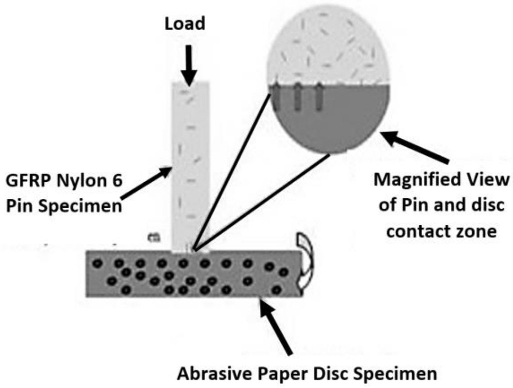


Fig. 10. Schematic representation of load sharing between fibers and the matrix.

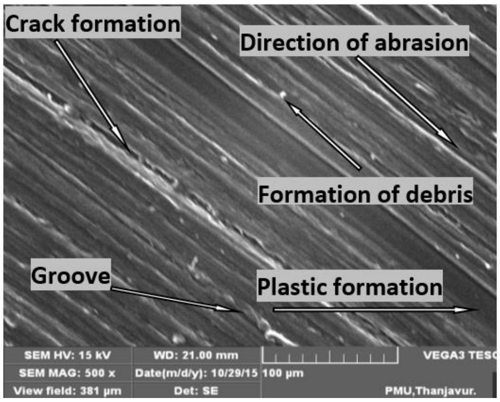


Fig. 11. SEM micrograph of worn surface at 20 N load of pure Nylon 6

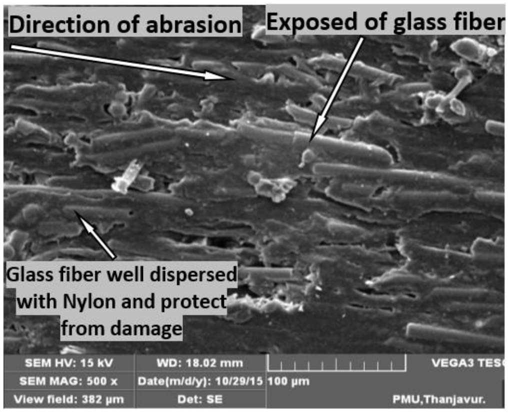


Fig. 12. SEM micrograph of worn surface at 20 N load of 30wt. % GFR Nylon 6

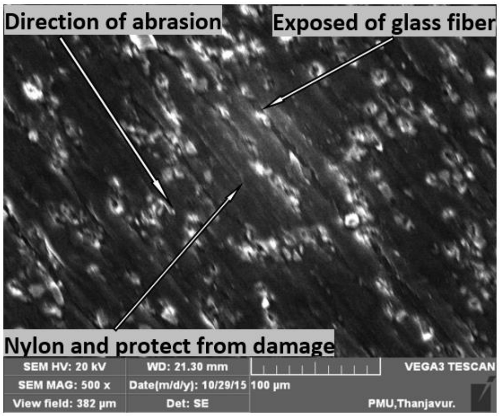


Figure 13. Optical microscopy of worn surface at 5 N load of 30wt. % GFR Nylon 6

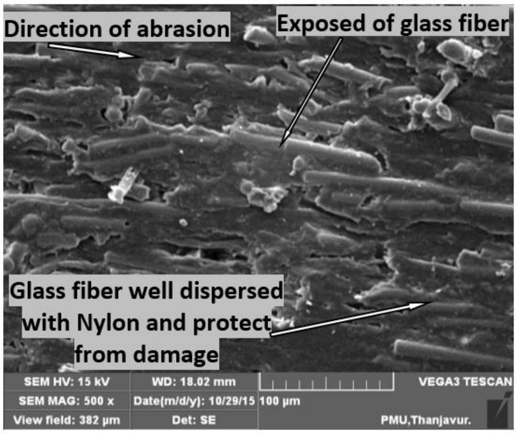


Fig. 14. Optical microscopy of worn surface at 20 N load of 30wt. % GFR Nylon 6

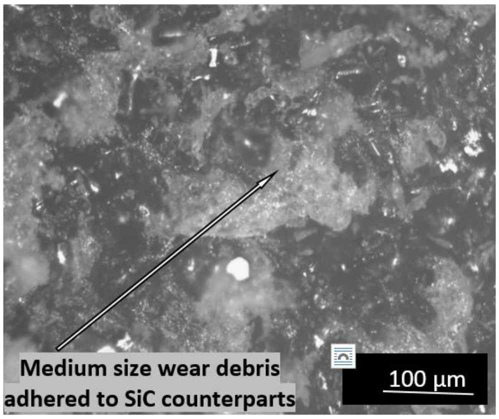


Figure 15. Optical microscopy of worn surface of abrasive paper at 125 m sliding distance.

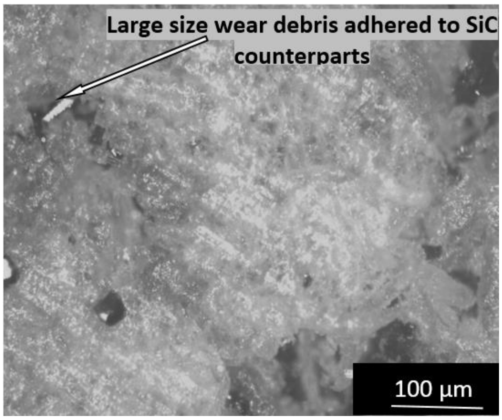


Figure 16. Optical microscopy of worn surface of abrasive paper at 500 m sliding distance

4. Conclusions

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

1) Dispersion of fibers in the matrix improves tensile strength and hardness of Nylon 6 material.
2) The weight loss of composites increases during increased loads, which is due to increased depth of penetration of the SiC grit on the material surface.
3) The weight loss of composites decreases with addition of glass fiber and lowest achieved at 30wt. % glass fiber.
4) The specific wear rate of composites decreases with increased sliding distances as the space between the abrasive filled by debris, reduces the depth of penetration of abrasive particles into the composites samples.
5) Plastic deformation and groves are primary wear mechanism for pure Nylon 6 cases; however addition of glass fiber reduces groves and plastic deformation. The worn surface of composites characterized by furrows.

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