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Investigation of Wear Behavior for Novel Polyamide 66 Composites Under Dry Sliding Conditions

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ABSTRACT

Polyamide 66 has been recently used in mechanical applications especially in gears manufacturing due to their low weight, low cost, and good tribological characteristics. In particular, great attention must be considered on the specific wear rate for polyamide 66 and their composites under dry sliding conditions. The goal of this paper is to study the effect of wear parameters; applied load, sliding distance and thermal effects on specific wear rate for neat polyamide 66 and their composites after adding 1% wt CNT or 30% wt (CF) under dry sliding conditions as well as, study the effect of the reinforcement materials on the hardness and their relationship to specific wear rate. The experimental result shows that the increase in wear parameters leads to increase the specific wear rate. However, with the addition of 1% wt CNT or 30% wt (CF) increasing the wear resistance by 130% and 200% under (30N) applied load and by 107% and 144% under (4000m) sliding distance respectively. Moreover, significant increase in hardness explained the enhancement in wear resistance. A scanning electron microscopy was done for the harmed specimen surfaces and the images appeared that the addition of reinforcement materials gives smooth surfaces with little harm unlike neat polyamide 66.

Keywords: Polyamide 66, CNT, Carbon Fibers, Specific Wear Rate, Hardness.

1. INTRODUCTION

Polymer and their composites become a very important material in the manufacturing of mechanical parts especially at recent years, which replaced metallic parts in many tribological applications due to their easily manufacturing, low weight, low cost as well as their excellent wear and corrosion-resistant [1]. Polyamide 66 or also known as nylon 66 is a new version of polyamides group that receives attention due to its unique properties such as high mechanical strength, rigidity, good wear-resistant and good stability under thermal and chemical effect [2]. Since polymer and their composites have been widely used in sliding application this necessitates understanding the wear behavior and mechanisms under variant sliding conditions [3].

Various researchers investigated the effect of adding fibers and nanoparticles as a reinforcement material to polymers and their effect on tribological characteristics, Meng *et al.*,, [4] study the effect of adding 1% wt of carbon nanotube (CNT) as a reinforcement material to polyamide 6 on wear behavior. They observed that the use of CNT as a reinforcement material increases the wear resistance due to transfer film generated between the pin and disc that work as a self- lubricant between the meeting surfaces. Li and Xia [5] investigated the wear behavior for polyamide 6 and their composites after adding CF with (10, 20, and 30 Vol %). The results show an increment in wear resistance up to 20% addition and decreased after that. Eleiche *et*

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al., [6] suggested a new polyamide 66 composite reinforced by 2% glass fiber (GF), 1% MoS_2, and 0.7% Mica platelets to overcome the tribological problems in rotating bands. The results indicate that the suggested composite has combination of strength, wear and heat resistance, as well as structural stability during service. Lee *et al.,* [7] investigated the effect of CNT length with 1% wt used as a reinforcement material to polyamide 66 on tribological properties. The results indicate that the long CNT addition gives better wear resistances than short and medium CNT. Moreover, the long CNT decrease the wear rate under range of temperatures up to 110°C after that will be increased. Kei Shibata *et al.,* [8] studies the wear behavior for polyamide 66 (PA66) reinforced by rice bran ceramics (RBC) particles at wide range of pressure-velocity (PV) values under dry conditions. The results show reduction in specific wear rate with the addition various weight fractions of RBC particles to PA66 by (55-86%) in comparison with pure polyamide 66. Sakka *et al.,* [9] study the influence of carbon nanotube and graphite fillers in epoxy resin on wear behavior, the results indicate that the addition of 1.5% CNT presents a great improvement in wear resistance. Guglani and Gupta [10] study the effect of adding micro titanium dioxide with different weight fraction to polyamide 66 on wear behavior under different parameters. They concluded that the addition of micro TiO_2 to polyamide 66 up to 6% wt leads to reduction of wear rate and they suggested using combination from 2% wt to 6% wt micro titanium dioxide with polyamide 66 for best performance in applications that need good tribological properties.

In the present work, the effect of different parameters such as applied load, sliding distance and elevated temperatures on specific wear rate of polyamide 66 and their composites were investigated after adding 1% wt CNT or 30% wt CF under dry sliding conditions. In addition, this research also studies the effect of the reinforcement materials on the hardness and their relationship to specific wear rate.

2. EXPERIMENTAL DETAILS

2.1 Materials

Polyamide 66 and their composites with 1% wt CNT or 30% wt CF were obtained from Guangzhou engineering plastic industries (group) Co. Ltd. was used to prepare wear and hardness test specimens.

2.2. Composite Preparation

The composites were prepared by injecting polyamide 66 with 1% CNT (purity: >95%, diameter: 20-25 nm, length: 25-40 μm) or 30% CF with (diameter: 10 μm, average length 260 μm) in rod shape with 120 mm diameter and 750 mm length.

2.3. Experimental Tests

2.3.1. Wear Test

Wear test for polyamide 66 and their composites were carried out by pin-on-disc tribometer as shown in Figure 1. In order to estimate the specific wear rate for the composite, the specimens were prepared according to ASTM G99-05 under dry sliding condition [11]. Cylindrical specimen pin (10 mm diameter and 20 mm length) and stainless-steel disc (AISI 314) with surface roughness 0.25-0.3 μm and 0.15 μm respectively were prepared for this purpose. On the other hand, in order to investigated the thermal effect on wear behavior, a small furnace with suitable dimensions was added to tribometer including (2000 watt) electrical heater fixed inside and K-type thermocouple used to control the internal temperature while the furnace outside was insulated with two layers of woven glass fiber to prevent heat leakage. The electrical furnace was connected to a digital thermal control unit board for the selection of testing temperature.

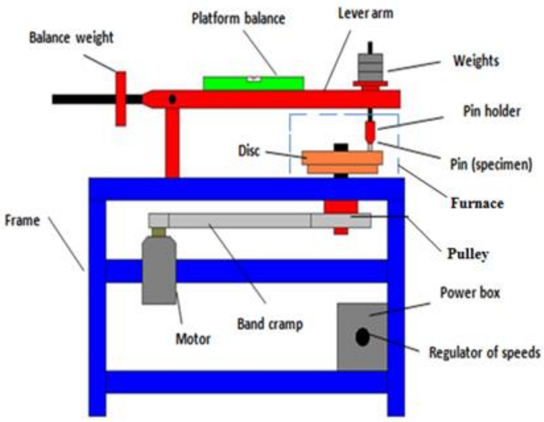

Figure 1. Schematic representation of pin-on-disc tribometer.

The test was carried out at a rotating speed 300 rpm, applied loads from 5 N to 30 N, variant sliding distances from 0.6 up to 4 km and range of temperatures from room temperature to 130°C. After the tests, the specimens cleaned and weighed by electrical balance (Radwag AS 160/C/2 with accuracy 0.0001g). For more accuracy, three tests were carried out under each test condition and the average values of specimen weight were used for further analysis. Scanning Electron Microscopy (SEM) was carried out for specimen surfaces in order to obtain more information about the wear mechanism under the effect of applied load at room temperature (T_R) and 130°C. The specific wear rate (S.W.R) was calculated using equation 1.

$$S.W.R = (\Delta m * 1000)/(\rho * W * X) \quad (1)$$

Where Δm the mass loss of the specimen (g), ρ is the specimen density (g/cm^3), W is the normal load in (N), and X is the sliding distance (m). Sliding distance X was calculated using equation 2.

$$X = \pi * D * n * t \quad (2)$$

Where D is the disc diameter (m), n is the rotational speed of disc (rpm), and t is the sliding time in (min) [2, 4].

2.3.2. Hardness Test

Hardness test was carried out for polyamide 66 and their composites using shore D hardness tester analogue DIN 53505 (Germany). A load of (44.64 N) was applied on the specimens, at least ten data was calculated to find the hardness for each specimen.

3. RESULTS AND DISCUSSION

3.1 Hardness Test

The variation in hardness of neat polyamide 66 and their composites are shown in Figure 2. The chart in Figure 2 indicates that the addition of 1% CNT or 30% CF to polyamide 66 leads to a significant increase in hardness. The results showed that the composite material prepared from polyamide 66 with 30% wt CF has higher hardness value than PA66/1% CNT composite due to the greater surface area of CF in contact with polyamide 66. The CNT made the first composite has higher bonding and thus will be harder.

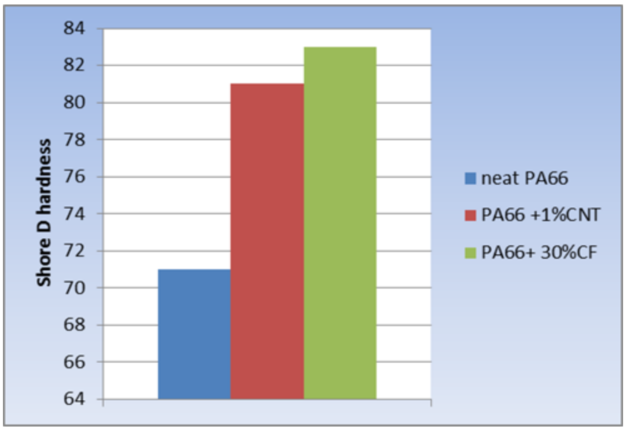

Figure 2. Shore D hardness test.

3.2. Wear Test

The variation in specific wear rate of polyamide 66 and their composites with various applied loads, sliding distances, and temperatures under dry sliding conditions was considered in this test.

3.2.1 Applied Load Effect

The specific wear rate of polyamide 66 and their composites with the increase in applied normal loads is shown in Figure 3. It can be seen that the specific wear rate of polyamide 66 composites always has lower value than neat polyamide 66 under the same sliding conditions, which indicates that the addition of reinforcement materials leads to improve the wear resistance.

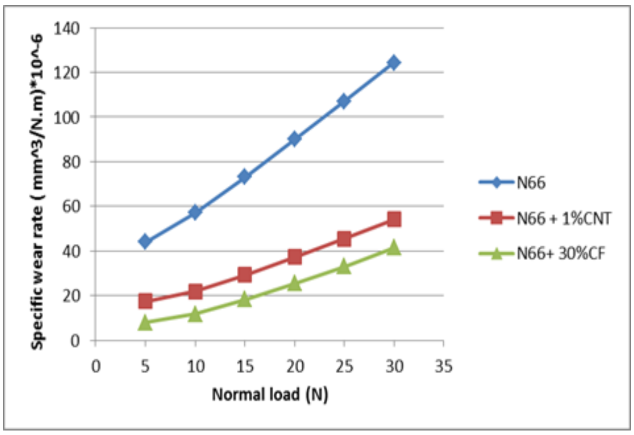

Figure 3. Effect of normal load on specific wear rate.

The increasing applied normal load increases the specific wear rate of polyamide 66 and their composites, which have a great agreement with the finding from previous researches where the specific wear rate direct proportionality to the normal load [5, 7&10].

It can be seen that the polyamide 66 composites with (1% CNT or 30% CF) have higher hardness than neat polyamide 66 as shown in Figure 2, which indicated that these composites have higher load carrying capacity than neat polyamide 66. Therefore, the material removal of these composites is more difficult and leads to an increase in the wear resistance by (130% and 200%) respectively under the highest normal load (30N).

3.2.2 Sliding Distance Effect

The effect of sliding distances on polyamide 66 and their composites were carried out under constant applied load equal to (30N). Figure 4 presents the variation in the specific wear rate of polyamide 66 and their composites under variant sliding distances. It can be observed that the wear resistance of polyamide 66 composites always higher than neat polyamide 66 under the same test conditions, which indicated that the addition of reinforcement materials leads to reduction of the specific wear rate.

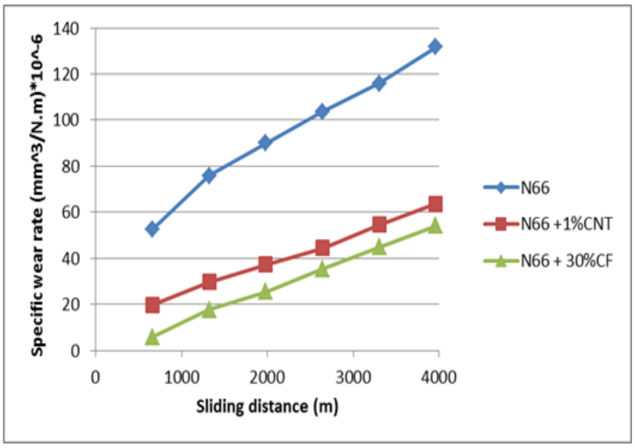

Figure 4. Effect of sliding distance on specific wear rate.

The increase in the sliding distance leads to an increase in the specific wear rate of polyamide 66 and their composites. As shown in Figure 4, the addition of (1% CNT or 30% CF) leads to a great enhancement in wear resistance by (107% and 144%) respectively under longest sliding distance (4 km). This enhancement was due to the strong bonding between the matrix and the reinforcement material which generated a transfer films between the specimen and the disc worked to prevent the polyamide 66 composites from the hard metal asperities.

3.2.3 Thermal Effect

The wear rate of polyamide 66 and their composites was tested as a function of temperature, which was examined at constant applied load and sliding distance equal to (30 N and 4000 m) respectively.

In order to obtain an approximately complete perception in wear behavior for polymers under thermal effect, the glass transition temperature (T_g) should be specified and the wear behavior before and after this temperature should be compared. Differential scanning calorimetry (DSC) test has been done to specify the T_g for polymer composites used in this research. The results indicate that the T_g for polyamide 66 and their composites approximately (50°C) and this value has a great agreement with [7, 12]. Based on this result, then the investigation of thermal effect on wear behavior was done from room temperature up to 130°C in order to obtain the general influence of temperature on wear behavior for polyamide 66 and their composites.

Figure 5 shows the specific wear rate behavior of polyamide 66 and their composites before and after T_g. The increase in temperature from room temperature up to 50°C leads to uniform increasing in specific wear rate. Moreover, the polyamide 66 composites have better wear resistance than neat polyamide 66 under the same test conditions.

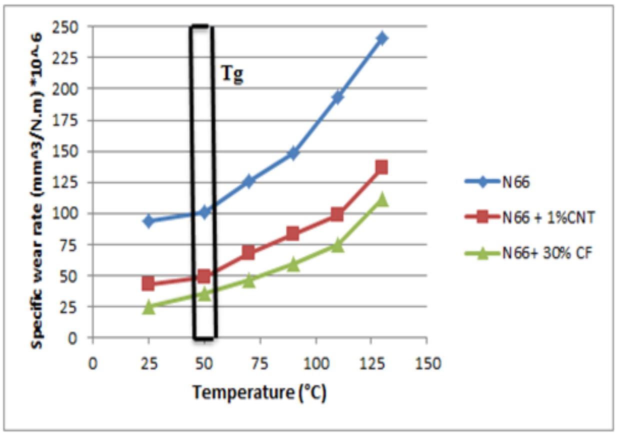

Figure 5. Effect of temperature on specific wear rate.

In Figure 5, after crossing $T_{g,}$ an explicit increase in specific wear rate especially in neat polyamide 66 was observed. However, at temperature closed to 90°C, a sharp increase was observed due to the softening in polyamide 66 asperities. In contrast, polyamide 66 composites have the same behavior with the neat polyamide 66 in range of temperatures below T_g. However, with the increasing in temperature up to 130°C, the specific wear rate gradually increases indicating that the addition of the 1% CNT or 30% CF help minimize the thermal effect and prevent polyamide 66 from softening with reduction in specific wear rate by 77% and 116% respectively.

3.3 Scanning Electron Microscopy

For more information about the wear mechanism that is generated due to the applied load before and after T_g scanning electron microscopy (SEM), a test was done on sliding surfaces of the pin specimens as shown in Figure 6. The harmed surfaces for polyamide 66 and their composites before T_g was showed in Figure 6 (a to c) while Figure 6 (d to f) display the harmed surfaces after T_g.

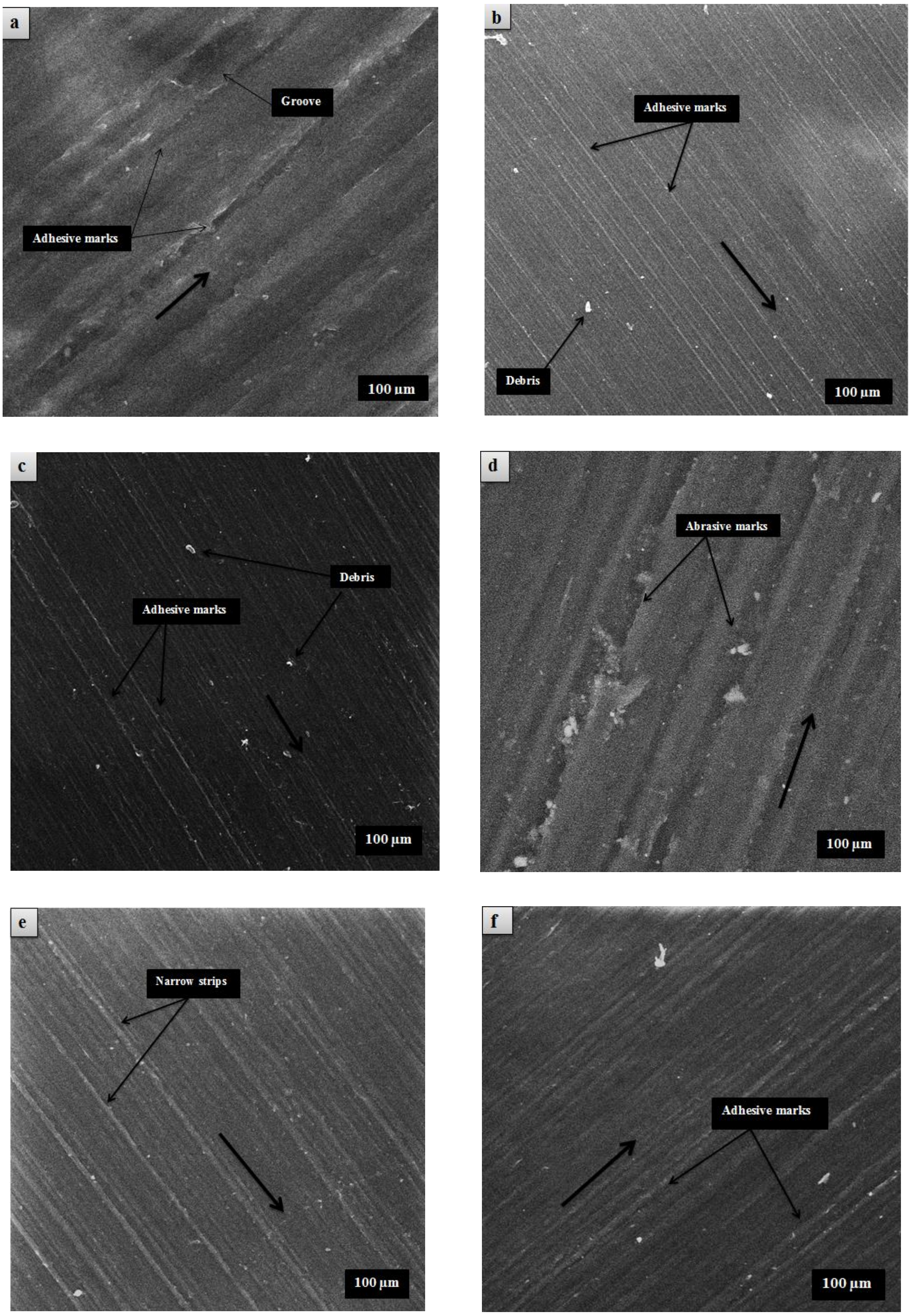

Figure 6. SEM images of the typical harm surfaces of (a) PA66 at 25°C, (b) PA66+CNT at 25°C, (c) PA66+CF at 25°C, (d) PA66 at 130°C, (e) PA66+CNT at 130°C, and (f) PA66+CF at 130°C.

As shown in Figure 6-a, the normal applied load leads harm in polyamide 66 specimen surface displayed adhesive marks in the direction of sliding with a small detachment of particles appeared as a groove in the contact surface. In contrast, a considerable reduction in harm and adhesion due to employing of CNT or CF in polyamide 66 is shown in Figure 6 b & c. A relatively smooth surface and a few adhesive marks were found which indicates the addition of nanoparticle or the reinforcing fibers improved wear resistance of the composite. Both CF and CNT particles serve as a solid lubricant to prohibit direct contact between the meeting surfaces. This observation was compatible with the fact that the addition of reinforcement materials made the composites harder and better resistance to detachment when sliding against the steel disc surface.

One of the most important necessities was conceived the wear mechanism of polyamide 66 and their composites at range of temperatures above T_g while considering their surface attitude under dry sliding conditions. As shown in Figure 6-d, the neat polyamide 66 suffered high wear rate when served under (130°C) and applied load equal to (30 N). The appearance of ploughed marks in sliding direction was significantly noticed and that indicated the occurrence of an abrasive wear mechanism and softening in the contact zone that leads to a rough harm surface. On the other hand, the polyamide 66 composites yield different behavior under the same test conditions as shown in Figure 6 e & f. The CNT particles lead to smooth surfaces with some narrow strips parallel to the sliding direction can be classified as adhesive marks and that classification have a great corroborate with behavior of CNT/polyamide 66 composite sliding at elevated temperature. In contrast, the employing of CF in polyamide 66 appeared as the best performance at elevated temperatures due to the enhancement in structural strength which leads to high resistance results from strong bonding between the matrix and fiber. In addition, the generation of transfer film at contact zone minimized the wear rate as possible and give smoother surface with little adhesive marks.

4. CONCLUSIONS

From the tribological study on polyamide 66 and their composites, the following conclusions can be obtained:

i. The addition of CNT and CF afford higher hardness values for polyamide 66 composites than neat polyamide 66.
ii. The increasing in wear test parameters; applied load, sliding distance and temperature lead to increase the specific wear rate for neat polyamide 66 and their composites by variant percentage.
iii. Despite increasing in applied load, sliding distance and temperature the addition of 1% CNT or 30% CF reduces the increase in specific wear rate with great reduction percentage in comparison with neat polyamide 66 under same test conditions.
iv. A slightly uniform increases in specific wear rate happened for polyamide 66 and their composites before the T_g while a rapid increase in neat polyamide 66 was seen after T_g with a steady-state increase for their composites due to the addition of reinforcing materials.
v. From the above results, the addition of 30% wt of CF to polyamide 66 gives the highest wear resistance and hardness under all the test conditions.

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