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Wear Behaviors of Micron Size Graphite Particle Reinforced Nylon Composite

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Abstract

Composites are wonderful materials in the sense of combining the properties of its constituents. The past decade has seen a renewed interest in developing more efficient low cost materials. In this regard, polymer composites have gained much more attention because of their light weight, low cost, ease of fabrication, corrosion resistance, and good wear properties and so on. Nylon, a polymeric material, is widely used in various tribological applications such gears and bushings used in household appliances, automobile speedometers, and windshield wipers, etc. In this study, the effects of micron size graphite powder reinforcement in nylon have been investigated by pin-on-disc type wear test. For making the composites, nylon beads were thoroughly mixed with 1 wt% graphite and they were then hot pressed. Wear samples were also made from hot pressed pure nylon (without the addition of graphite). Then, wear tests were carried out at a fixed 2 kg dead load with 500 rpm under dry sliding condition. It has been revealed that addition of graphite particles significantly reduces the wear rate of the composites. Interestingly, the reduction in wear rate of nylon-based graphite composite was more pronounced with wear time. Wear mechanism has also been found different in these both cases.

Keywords: nylon, graphite, reinforcement, wear, micron size, hot press

1. Introduction

Polymers are widely used in many applications including tribological applications such as gears and cams where its wear behavior is of utmost importance. Introducing self-lubricating agents in polymers is a viable method of improving its wear characteristics and minimizing the use of oil or grease, as these lubricants can alter surface properties and cause contamination. Overall this can reduce the wear damage and increase the product life. Many of these avenues have already been explored by researchers [1].

Nylon is extensively used as tribological polymers due to its good combination of thermal, mechanical and tribological properties [2-5]. Formability, low cost and availability of nylon are also advantages over other engineering polymers [6]. But some modification is required in pure nylon when it is used in sliding-contact applications because it has a high co- efficient of friction which leads to high wear rate [7]. Hence, application becomes restricted in high load and low temperature environments [8-10].Studies have shown that if a filler material of self lubricating nature is added, it prevents or minimizes instabilities in the slip-stick motion[11],which serves to improve its wear property. PTFE and graphite are the most important solid lubricants that can be used to improve the tribological properties of nylon by synergistic reactions. Several efforts have been made in this regard to investigate the effects of said additions to nylon. Graphite has a structure similar to mica, where atoms bond strongly to form sheets but the sheets have weak van dar walls bond between them which makes the sheets easily able to slide past one another, giving graphite it's amazing lubricating nature, provided the temperature is within the tolerance level [12]. They can be easily fragmented under gliding conditions by shear forces. This produces a transferred film on the part being worn and reduces wear [13]. So, graphite tends to ameliorate the tribological properties when it is used as reinforcement in a polymer matrix composite [14]. This kind of composites can endure operating temperature up to 300°F [15].Graphite, as reinforcement, has been used for improving the wear properties of materials. One study showed that glass- epoxy composite containing graphite has greater resistance to wear in the pin-on-disc sliding condition than the control/neat glass- epoxy composite [16]. In another study, it was seen that the friction co-

efficient and wear rate decreases continuously with graphite addition in polyphtalazinone ether sulfone ketone (PPESK) composites. Least amount of wear rate and friction co- efficient was found when graphite content was above 20 wt % [17].Thus, considering the effect that graphite powder has in improving the wear property, it is worth investigating its effect on nylon matrix composites.
In this study, hot pressed pure and composite samples were prepared and wear rates were measured using pin-on-disc method for comparing the tribological properties.

2. Experimental procedures

2.1 Materials

In this experiment, nylon beads were used as base material and micron sized graphite powder was used as the reinforcement. Both of these were collected from the local market. Information about the materials is given in Table 1.

Table 1. Data for the materials used in this study

Material	*Form*	*Supplier*	*Density, gm/cm3*
Nylon	Beads	Local market	1.13
Graphite	Powder	Local market	2.20

2.2 Sample preparation

For producing the pure sample, nylon beads were taken in a circular mould coated with mould spray which helps in easy ejection. 20 gm nylon beads were used for each sample. The mould was placed in the hot pressing machine where temperature and pressure were simultaneously applied on the beads. Temperature was set to 220°C which is the melting temperature of nylon. Temperature was gradually increased in the machine and when 220°C was reached, pressure was removed for a while, so that any gas produced/trapped inside the mould can come out which, otherwise, can cause bubbles to form. After that pressure was applied again and the temperature was further increased to 225°C so that complete melting occurs. When 225°C was reached, temperature of the machine was brought down to room temperature. Upon completion of solidification the nylon disc was ejected from the mould. The procedure is shown as pictures in figure 1.
For producing the composites similar procedure was followed. But in this case, 1wt% micron sized graphite powder, which is 0.2 gm, was taken in a beaker containing acetone. With a stirrer, a homogeneous solution of acetone and graphite was prepared, and then 20 gm nylon beads were introduced into the mixture. The mixture was stirred again to develop a uniform layer of graphite surrounding each bead. Then this mixture was poured into the mould and composite sample was prepared following the same schedule as the pure ones. Fig 1 and 2 shows the procedures in a simplified way. For making the pin (sample) and the disc, different sized moulds were used. Pictorial flow chart of composite making is given in figure 2.

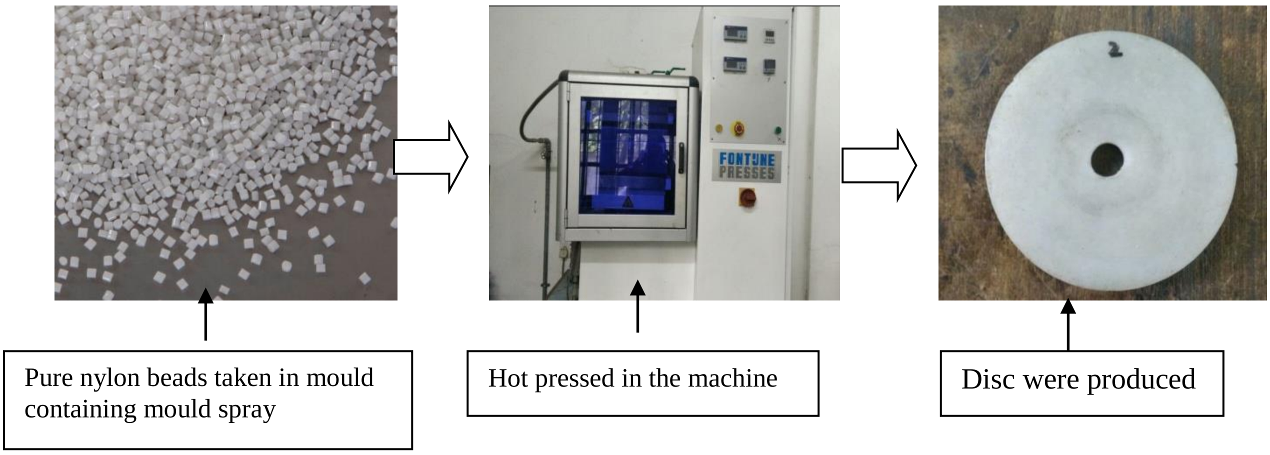


Fig. 1. Pictorial flow chart of pure nylon disc preparation

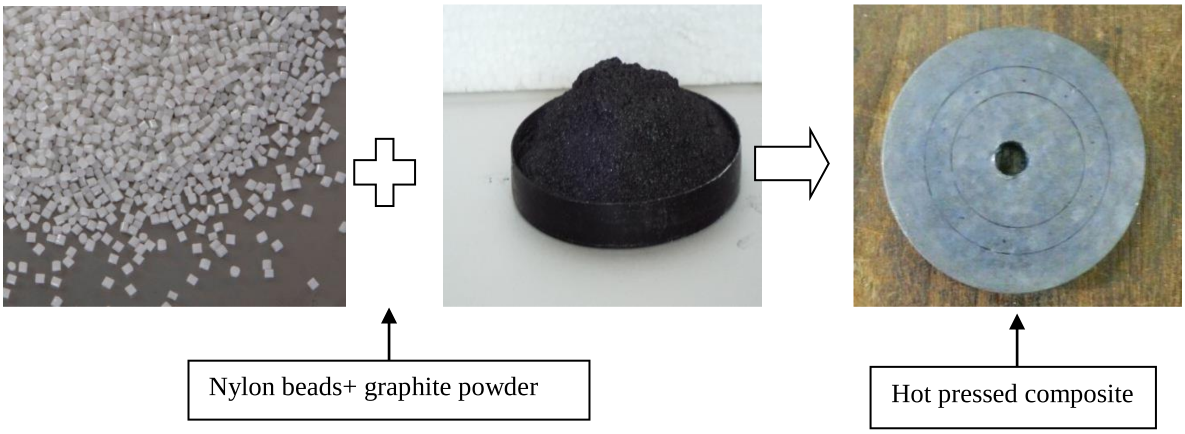


Fig. 2. Pictorial flow chart of graphite reinforced nylon disc preparation

2.3 Wear test procedure

Pin-on-disc type test apparatus was used under dry sliding condition for the wear test. Both the pin and the disc were composed of same material. Samples were 6 mm in diameter and 20 mm in height and were cut from the previously casted samples. Initial sample weights were taken. Then the samples were put in the sample holder and pressed against the disc with 2 kg of dead weight. The disc was rotated at a speed of 500 rpm. Apparatus set up is shown in figure 3.

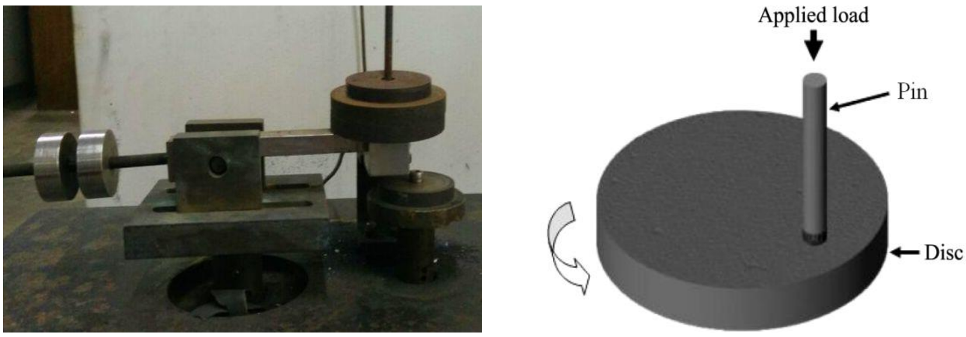


Fig. 3. Pin-on-disc test apparatus

Tests were conducted in this way for 1, 2, 4 and 8 hours for pure and composite samples of same dimension. Every time, after the machine was stopped, samples were cleaned and weight was taken and compared with the initial value for determining weight loss.

3. Result and discussion

Table 2 and Table 3 show the weight loss and wear rate of the pure and composite sample under dry sliding condition respectively. In Figure 4 (a) and 4(b), the results are shown in a graphical form for easier comparison.

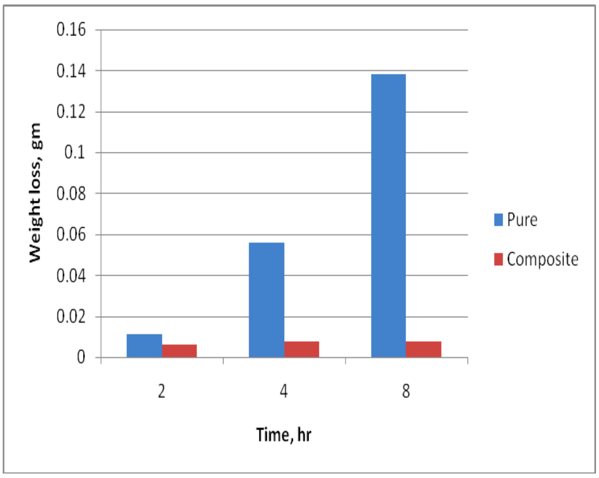
Table 2. Pure sample wear test data

Time, hour	*Weight loss, gm*	*Wear rate, gm/hour*
2	0.011	0.005
4	0.056	0.01
8	0.1382	0.02

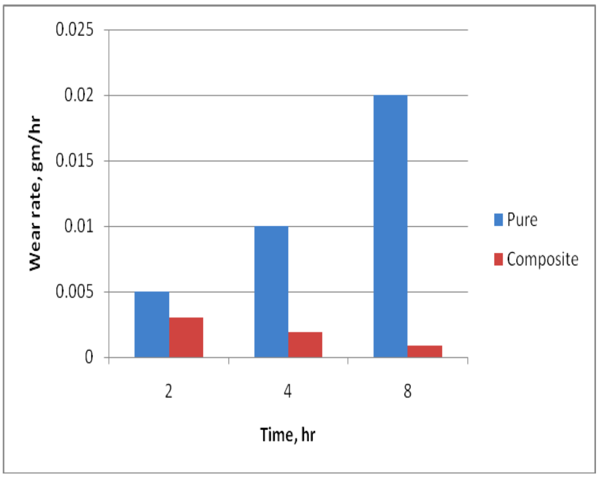
Table 3. Composite sample wear test data

Time, hour	*Weight loss, gm*	*Wear rate, gm/hour*
2	0.0062	0.003
4	0.0074	0.0019
8	0.0078	0.0009

It was found that, with the increase of time, mass loss and wear rate of pure sample increased rapidly during prolonged exposure to the sliding action. But from the same figures, we can see that, wear rate gradually decreased for the composite sample compared to the pure sample, with continual exposure to sliding action. Graphite addition, thus, had a remarkable effect on the wear properties of the samples.



(a)



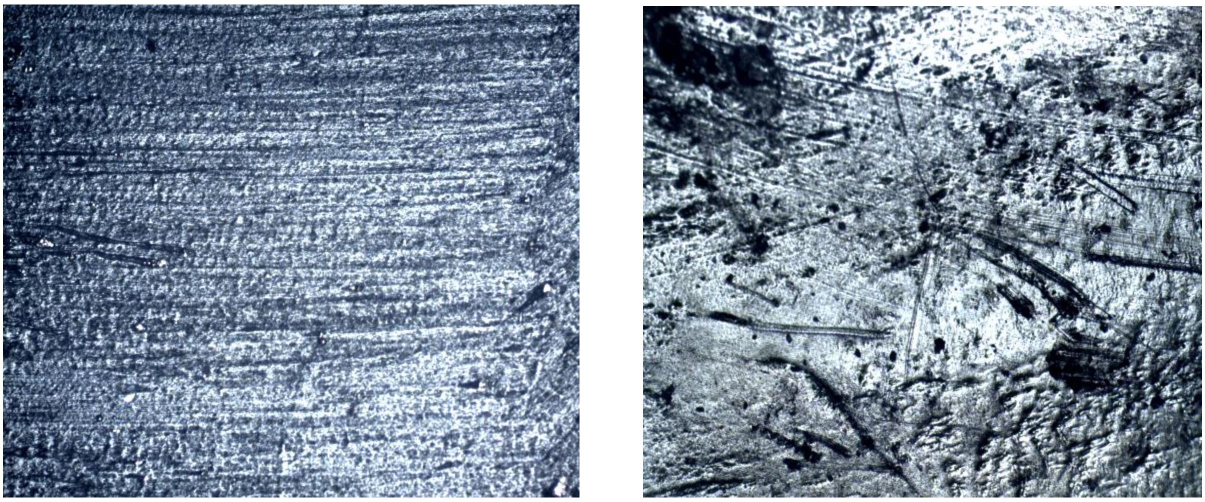
(b)

Fig. 4. (a) Weight loss, (b) Wear rate of pure and composite sample with time

Both micro and macro photographs were taken before and after wear of the samples. After 8 hours of wear, macro pictures of the worn surfaces of the disc showed that a clear wear track was produced (Fig. 5). Wear track was more prominent in the pure sample due to increased wear rate.

Fig. 5. Macro pictures of the discs after wear; pure nylon (left) and composite (right)

Micro graphic pictures of sample surfaces after 8 hours of wear are shown in Fig 6. We can see that, pin surface of the pure sample has undergone severe wear under dry sliding condition. Prominent wear marks are left in the worn surface in a continuous pattern. These marks were produced mainly due to the fragmentation of the pure nylon matrix. This phenomenon was due to the accumulation of heat during sliding friction. The heat may be produced due to the damping of shear waves inside the pure sample during sliding. The high frequency increases the surface temperature and can cause sub surface melting and recrystallization. The shear wave is accelerated by the frictional process [18]. So, surface softening or melting and recrystallization may have occurred during that period and caused the ejection of larger worn pieces from all over the surface as there was no barrier to wear. Two body abrasions occurred between the pin and disc. Indirect effect such as thermal expansion of nylon due to internal heating can also increase the wear rate [19].This kind of trend was seen in the past [20]. These mechanisms can be attributed to the massive wear observed.



(a) (b)

Fig. 6. Micrographic picture of the pin surfaces after 8 hours wear of (a) pure sample (b) composite sample

But in Fig 6(b), we can see that there is no such continuous wear pattern in the surface. Wear has occurred in distinct, separated places. Wear has also become very limited. Main reason for this was the self lubricating nature of graphite filler. It has done that by adhesion with the counteracting surfaces or formation of thin transfer film of graphite with low shear strength at the interface of the sliding surfaces. It caused the two surfaces to slide past each other having low frictional co-efficient. With the progress of time, the film got thicker and reduced friction and mass loss. Some places that have undergone wear may have experienced wear due to the absence of graphite accumulation in those areas.

Thus we can see that, in case of composite, two body abrasion has been converted to three body abrasion due to the presence of those loose graphite powders, which eventually form a film. It is found that, three body abrasion is slower than two body abrasion, because in two body abrasion process, particles or asperities get strongly attached between the sliding surfaces. But in three body abrasion, the particles are loose and they can freely roll. Thus, three body abrasion produces lower wear rates because the contact type between the abrasive particle and the sliding surfaces is rolling rather than sliding [21,22]. Due to this reason, the composite underwent less wear than the pure sample and wear rate was improved.

4. Conclusion

In this work, wear behavior of micron sized graphite powder reinforced in nylon matrix has been investigated and compared with the wear profile of pure nylon sample. From this study, following things have been observed:

- Graphite, present in the composite, creates a lubricating medium between the dry sliding contacting surfaces during wear
- It dramatically reduces the friction between the contacting surfaces
- Mass loss due to wear is greatly reduced by this self lubricating nature of graphite

Wear rate improves in the composite sample compared to the pure sample

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