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Investigation of the influence of solid lubricants on the tribological properties of polyamide 6 nanocomposite

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ABSTRACT

The tribological properties of nano titanium dioxide filled polyamide 6(TiO_2/PA 6 nanocomposite, 5/95 by weight) and its composites filled with single and combined solid lubricants were systematically investigated. It was found that all the solid lubricants except molybdenum disulfide (MoS_2) could significantly enhance the tribological performance of TiO_2/PA 6 nanocomposite; and the nanocomposite filled with polytetrafluroethylene (PTFE) exhibited lower friction coefficient and wear rate than that filled with ultra-high molecular weight polyethylene (UHMWPE); but it was interesting that the nanocomposite filled with MoS_2 combined with UHMWPE had better tribological performance than that filled with MoS_2 combined with PTFE, and the nanocomposite filled with MoS_2 together with both UHMWPE and PTFE performed the best among the combination solid lubricants. XPS and SEM results showed that the synergism of fillers in helping the formation of thin, uniform and continuous transfer film was responsible for the enhancement in tribological properties.

1. Introduction

PA 6 is a kind of important engineering plastic which is widely used in friction material field, and recently its nanocomposites have received much attention since the significant improvements in tribological properties that led by nanoparticles [1–3]. However the high surface energy of nanoparticles will usually result in irreversible aggregation, which may plow on the counterpart steel ring and lead to high friction coefficient [4].

It is well known that solid lubricants exhibit self-lubricating behavior and their applications in sliding prevent stick-slip motion instabilities. The solid lubricants such as molybdenum disulfide (MoS_2) [5–7], ultra-high molecular weight polyethylene (UHMWPE) [8], polytetrafluroethylene (PTFE) [9,10], graphite [11] and graphene [12] have been thus widely used to enhance the friction and wear properties of polymers. Synergistic effects are usually obtained between solid lubricants which are useful for improving the tribological properties of polymer composites [13,14]. But not all cases can solid lubricants improve the tribological properties of polymers. Since solid lubricants sometimes reduce the mechanical properties of the composites, the decrease in mechanical properties will adversely affect the wear resistance [15,16]. Delightfully, this problem can be resolved by incorporating reinforcing agents such as fibers [17] and nanoparticles [18]. In this case, solid lubricants may facilitate the formation of the transfer films while the reinforcing agents enhance the deformation resistance and plow resistance of the polymer composites, consequently the synergistic effects between different fillers are obtained which are useful for improving the tribological properties of polymer composites.

Though the reinforcing agents and the solid lubricants usually showed a positive hybrid effect [19–24] on enhancing the performance of polymers, it was not necessarily true. The tribological properties closely depended on the compositions and the tested conditions [25–27]. Whilst the synergistic effects between combined solid lubricants and TiO_2 have not systematically studied.

With those perspectives in mind, a series of PA 6 nanocomposites which used nano-TiO_2/PA 6 (5/95 by weight) as polymer matrix, and different combinations of MoS_2, UHMWPE and PTFE as fillers were prepared and their tribological properties were systematically investigated. The objective of this work is to discuss the synergism of the multiple fillers in the composite on the improvement of tribological performance.

2. Experimental

2.1. Materials

TiO_2/PA 6 nanocomposite (5/95 by weight) was used as matrix, the model of PA 6 in the composite were PB1006 LM BN 70745; the nano-TiO_2 (RCL-69) particles in the composite had an average diameter of 1–37 nm. The average size of Molybdenum disulfide

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(MoS_2) was 10 μm and PTFE was less than 1 μm. The average molecular weight of UHMWPE was 3–6 million.

2.2. Specimens preparation

The blend of TiO_2/PA 6 and its composites with solid lubricants were achieved by using twin-screw extruder ($\Phi=35.5$ mm and $L/D=41$) with a screw frequency of 360 rpm and a feeding frequency of 20 Hz under processing temperatures of 210, 220, 230, 240, 240, 240, 240, 240 and 240 °C in nine zones of the extruder barrel. The extrudate was continuously cooled by water and pelletized. The granule was dried in a vacuum oven at 60 °C for 12 h again and subsequently injection molded (on a HTF160J/TJ injection machine) to tribological test samples with a dimension of $25\times25\times15$ mm^3 according to the size of specimen clamp on the tribometer. The injection pressure was 85 MPa, the dwell pressure 20 MPa and the dwell time 4 s. The temperatures in four zones were 250, 250, 250, and 250 °C and in the nozzle 230 °C.

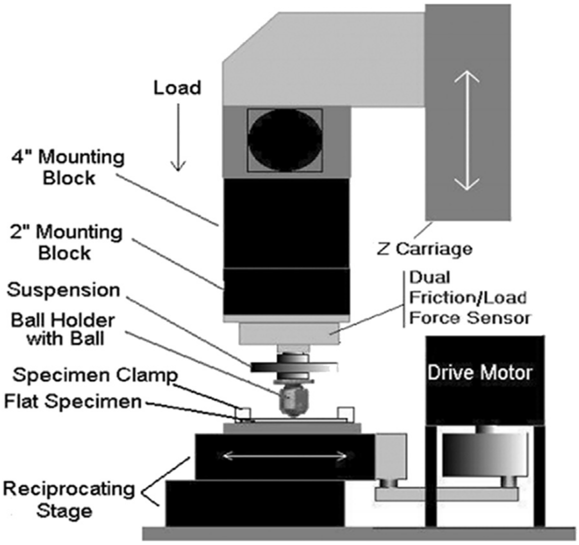

Fig. 1. Schematic diagram of ball-on-flat tribometer.

2.3. Wear test

Friction and wear test were carried out on an UMT-3 (Universal Macro Materials Tester, Fig. 1) ball-on-flat tribometer. An assembly diagram of the friction pairs was shown in Fig. 2, the ball up specimen (HRC 62) with a diameter of $d=9.5$ mm used as counterface, consisted of 440-C stainless which contains about 17.5% chromium. The load was applied downward through the ball counterface against the flat tested specimen mounted on a reciprocating drive. The surface were cleaned ultrasonically with acetone and thoroughly dried before testing. All the test were performed in normal laboratory environment (temperature: 20 ± 5 °C, humidity: $50\pm10\%$) with four loads: 40 N, 60 N, 80 N and 100 N and at four velocities 200 rpm, 500 rpm, 1000 rpm and 1500 rpm (one motion period of forward and backward is defined as one round, and the stroke is 10 mm) which were based on the use condition (low load and low velocity) of the products. The test duration ranged from 0 min to 120 min. The friction coefficient was recorded and calculated by the ratio between the tangential force (Fx) and normal load (Fz), which obtained directly from the equipment. The average values of friction coefficient in the test range were used as the friction coefficient of samples. The width of the wear track b (see Fig. 3) was measured with a KH-7700 digital microscope to an accuracy of 0.001 μm. Then the wear rate was calculated using the following equation:

$$Wear\ \ rate=\frac{\Delta v}{Ld}=\frac{B}{Ld}\left[\frac{\pi r^2}{180}\sin^{-1}\left(\frac{b}{2r}\right)-\frac{b}{2}\sqrt{r^2-\frac{b^2}{4}}\right][\mathrm{mm}^3/\mathrm{Nm}]$$

where B is the trace of friction (10 mm), r is the semi diameter of the chromium steel ball (mm), b the width of the wear trace (mm), L the load (N) and d the sliding distance (m).

Each test was repeated three times, the maximum variation between these experimental values was controlled within ±15%. The data represented in this paper were the arithmetic mean values of the tests.

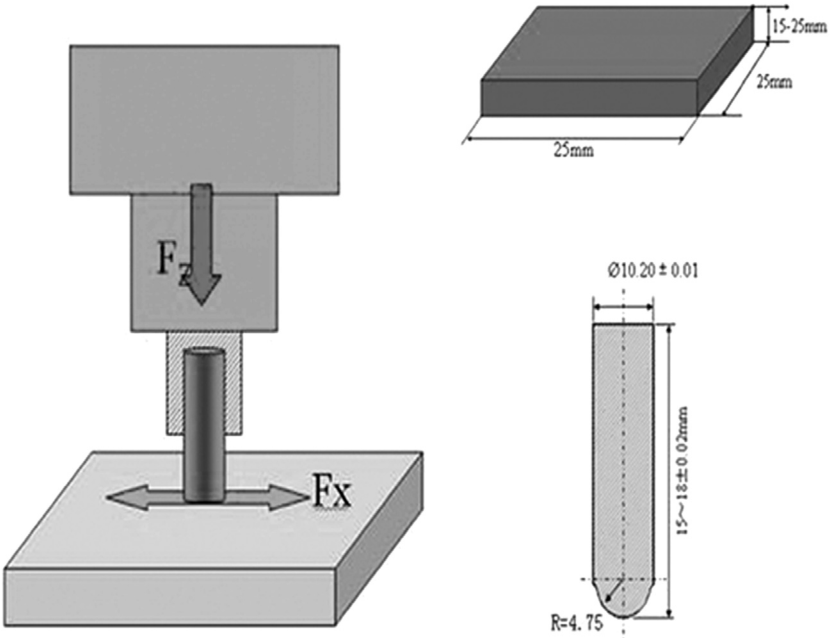

Fig. 2. Schematic diagram and sample size for the frictional couple Fz-load direction; Fx-friction direction.