Friction and wear of carbon nanohorn-containing polyimide composites


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Received 19 September 2004; accepted 13 March 2005

Polyimide (PI)-based composites containing single-wall carbon nanohorn aggregate (NH) were fabricated using the spark plasma sintering (SPS) process. For comparison, composites with carbon nanotube (NT) and traditional graphite (Gr) were also fabricated. The NH was produced using CO2 laser vaporization and a graphite target while the NT was produced by a chemical synthesis method. We evaluated the friction and wear properties of the PI-based composites with a reciprocating friction tester in air using an AISI 304 mating ball. NH drastically decreased the wear of PI-based composites; the specific wear rate of composite with NH of only 5 wt% was of the order of 10−8 mm3/Nm, which was two orders of magnitude less than that of PI alone. The wear reduction ability of NT seemed to be slightly inferior to that of NH, although it was considerably better than that of Gr. NH and NT lowered the friction of composites. The friction coefficient of composite with 10 wt% NH was less than 0.25, although it was slightly higher than that of composite with 10 wt% Gr. There was no clear difference in the friction reduction effect of NH and NT. The further addition of Gr to composites with NH or NT rather deteriorated the antwear property of composites, although the friction coefficient was slightly reduced. The transferred materials existed on the friction surface of the mating ball, sliding against composites with three types of carbon filler. These transferred materials seemed to correlate with the low friction and wear properties of composites.

KEY WORDS: carbon nanohorn, carbon nanotube, graphite, polyimide, composite, friction, wear

1. Introduction

The discovery of carbon nanotubes [1] has attracted widespread interest and many studies on mass production, evaluations, and applications have been conducted. Recently, a single-wall carbon nanohorn (SWNH), part of the carbon nanotube family, was produced by CO2 laser vaporization of graphite at room temperature [2,3]. The individual SWNH is a horn-shaped sheath composed of single-wall graphene sheet, 2–4 nm in diameter and about 50 nm long. The SWNH always aggregates to form a spherical particle with multiple horns; the average diameter is 80–100 nm.

The SWNH aggregate (NH) has good properties such as high adsorption, easy chemical modification, and high electric conductivity. Its high adsorption is especially attractive for fuel cell technology. Besides those properties, the NH is expected to display good tribological properties, because of its spherical shape with sub-micron diameter. However, the tribological properties of NH have scarcely been studied, even though those of carbon nanotubes have been considerably determined [4–14]. We have therefore been investigating the tribological properties of NH as an additive in grease and polymer-based composites.

In this paper, the friction and wear properties of NH-containing polyimide composites are reported and compared with those of composites with carbon nanotube and graphite. The tested composites were fabricated by the spark plasma sintering (SPS) process; their friction and wear properties were evaluated using a reciprocating friction tester in air.

2. Experimental

2.1. Composites

NH was produced using CO2 laser vaporization and a graphite target as detailed elsewhere [2,3]. Ar was used as the buffer gas and was filled in a reaction chamber to a gas pressure of 0.1 MPa. TEM and SEM images of NH are shown in figure 1. The average NH had a diameter of 80–100 nm. As a carbon nanotube, multi-wall carbon nanotubes (NT) produced by a chemical synthesis method using hydrocarbon and ultrafine catalyst particles were used [15]; they were 10–50 nm in diameter and several μm long (figure 1). The graphite used was commercially available graphite powder with
an average size of 0.6 μm, T-1 (Nippon Graphite Industries, Ltd.). Polyimide (PI) used as a base material was Kerimid 1010 (Nippon Polyimide Co.) with a powder size of less than about 50 μm.

PI-based composites were made using the SPS process. This process is a pressure sintering process utilizing on–off DC pulse energizing (figure 2), as detailed elsewhere [16,17]. The PI powders and carbon fillers were blended with a stirrer in ethanol and then dried. Blended powders were laid as the carbon-containing surface layer on PI substrate powders in a graphite mold of SPS. The composite was then sintered at a pressure of 50 MPa and a temperature of 220 °C, which was monitored by a thermocouple inserted into the mold, for 5 min. Some composites were sintered at higher temperatures such as 250 and 280 °C, but cracks were found in the sintered composites and their antwear properties were worse. Composites were 20 mm in diameter and 6-mm thick, with a 1-mm thick carbon-containing surface layer. The surfaces of composites were ground by emery paper of different abrasive particle sizes, and then polished with alumina slurry (powder size: <2 μm). The average surface roughness Ra of polished composites ranged from 0.02 to 0.05 μm; the roughness seemed to increase with higher carbon filler content.

The polished composite surfaces observed using an optical microscope are shown in figure 3. The carbon fillers dispersed in the boundaries of PI powders, although some filler cohesion was seen. The Vickers hardness of some composites was measured at a load of 0.49 N (figure 4). The hardness of composites with 10 wt% NH and 10 wt% NT was significantly higher than that of PI alone; the composite with NT seemed to be slightly harder than the NH-containing composite. The hardness of composite with 10 wt% Gr, on the other hand, was a little lower than that of PI alone.

2.2. Friction tests

Friction and wear tests were done using a ball-on-block type reciprocating friction tester. The mating was an austenitic stainless steel (AISI 304, \(H_v = 2.7\) GPa) ball of 9.2 mm diameter. The reciprocating friction stroke was 10 mm and tests were conducted at normal loads of 5 and 25 N. Average sliding speed was 20 mm/s (60 cycle/min) and the number of cycles was 7200. The test environment and temperature were ambient air and room temperature, respectively. During the tests, the friction coefficient was continuously measured using a load cell. The wear volume of the composite was calculated by measuring wear scars with a non-contact type surface profilometer. Two tests were conducted to examine the scatter of friction coefficient and wear rate, except for some cases.