

Tribological properties of aligned film of amorphous carbon nanorods on AAO membrane in different environments

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Received 11 July 2004; received in revised form 22 January 2005; accepted 2 February 2005

Available online 10 May 2005

Abstract

The aligned film of amorphous carbon nanorods was synthesized by chemical vapor deposition at 650 °C with the Co catalyst on a porous anodic aluminum oxide (AAO) membrane. The morphology and microstructure of the aligned film of amorphous carbon nanorods were examined by field emission SEM, TEM and Raman spectroscopy. The tests sliding against a quenched-and-tempered GCr15 steel were conducted using a ball-on-disk tribometer at an applied load of 980 mN and a sliding velocity of 0.2 m s⁻¹ in vacuum, humid air (RH 60%) and oxygen-rich environments. The tribological properties of the aligned film of amorphous carbon nanorods on the AAO membrane were influenced by the test environment. As compared to the tests in humid air and oxygen-rich environments, the aligned film of amorphous carbon nanorods showed slightly higher friction coefficient in vacuum, but exhibited higher wear resistance at the same time due to the absence of tribochemical reaction. The mass loss of the aligned film accelerated by the effects of oxygen and atmospheric humidity in humid air due to tribochemical reaction.

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Keywords: Tribological properties; Aligned film; Amorphous carbon nanorods; Environment; Anodic aluminum oxide (AAO) membrane

1. Introduction

Aluminum and its alloys are promising candidates for engineering application in many aspects, however, poor friction property and wear resistance restricted their applications in the industry where required sliding contact. Anodic oxidation and ion implanting have been used to modify the surface performances of aluminum [1,2]. In recent years, the solid lubricant coating processing technology and some compound nanowires synthesized on the porous anodic aluminum oxide (AAO) template have attracted considerable interest [3,4]. It was recognized that the AAO membranes were potentially advantageous as lubricant reservoirs. The nanometer lubricants, such as MoS₂ impregnated into the pores on AAO

membrane had low friction coefficients under normal conditions [5].

Many experimental results have indicated that the amorphous carbon (a-C) coatings, containing high sp³ bond could improve the friction and abrasion properties in ambient air [6–9]. But when the test environment varied, such as in vacuum or during the air-to-vacuum transition, the friction coefficients increased rapidly and the amorphous carbon coatings failed within a short sliding distance [10].

By adjusting the pore size on AAO membrane and the gas–solid reaction conditions, the carbon nanotubes and amorphous carbon nanorods could be prepared controllably by catalytic chemical vapor deposition (CCVD) [11,12]. The aligned films of carbon nanotubes and amorphous carbon nanorods presented low friction coefficient and better wear resistance under dry conditions, and the adhesion between the aligned film and AAO membrane remained intact [13,14]. In the present work, the tribological properties of aligned film

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of amorphous carbon nanorods in vacuum, humid air and oxygen-rich environments were investigated. The worn surfaces at different critical moments during friction tests were discussed.

2. Experimental

Samples of 99.999% purity aluminum with 30 mm in diameter and 2 mm in thickness were cleaned by ultrasonic oscillation in a mixture solution of acetone, dichloromethane and ethanol (1:2:1). These samples were then annealed at 500 °C for 4 h, and electropolished in an aqueous solution of sulfuric acid and phosphoric acid. Porous anodic aluminum oxide (AAO) membranes were fabricated by a two-step anodization in a solution of 0.3 M oxalic acid under a constant cell potential 40 V at 15 °C. After first anodization for 40 min, the anodic oxide layers were eroded in a mixture solution of phosphoric acid (6 wt.%) and chromic acid (1.8 wt.%) at 65 °C for 18 min. The specimens were anodized again for 2 h, and then dipped into an aqueous solution of phosphoric acid (5 wt.%) at 50 °C for 20 min to adjust the pore diameter.

A transition metal Co was electrodeposited in the ordered nanopores of the as-prepared AAO membranes after being pretreated in a sensitizing solution of SnCl_2 and in an activating solution of PdCl_2 . An acetylene–nitrogen mixture (1:1) was introduced into the quartz chamber at a flow rate of 200 ml min⁻¹. The aligned film of amorphous carbon nanorods was synthesized by catalytic chemical vapor deposition at 650 °C on the AAO membrane. The surface morphology and microstructure of the as-deposited film were characterized by field emission scanning electron microscope (SEM) equipped with energy dispersive X-ray spectroscopy (EDS), transmission electron microscope (TEM) and laser Raman spectroscopy.

The tribological properties of the aligned film of amorphous carbon nanorods on the AAO membrane in different

environments were investigated by WM-2002 ball-on-disk tribometer. The WM-2002 tribometer equipped with an organic glass chamber is consisted of loading lever, specimen holder, drive motor, air pressure monitored system and measuring equipment. During the experiments, friction force was recorded on line via torque as measured by the strain gauge mounted in the vertical arm. The friction coefficient was calculated by dividing the friction force, which was recorded on line via torque as measured by the strain gauge. In the organic glass chamber, the testing environments can be adjusted by deflating to be vacuum or introducing the desired gas. In the present work, the as-deposited film specimen served as the disk, and the ball fabricated by quenched-and-tempered GCr15 steel with Rockwell C hardness of HRC62 was 3 mm in diameter. The tests were conducted at an applied load of 980 mN and a sliding velocity of 0.2 m s⁻¹ in vacuum, humid air (relative humidity 60%) and oxygen-rich environments, and the friction coefficient was recorded on-line. The degree of vacuum was 1×10^{-2} Pa, and the background pressure of oxygen filled in the test chamber after being deflated to be vacuum was 0.8 atm (standard atmospheric pressure). After testing, the worn surfaces of the specimens were examined using field emission SEM and laser Raman spectroscopy.

3. Results and discussion

3.1. Morphology and microstructure

A SEM image of porous AAO membrane after pore-enlargement treatment is shown in Fig. 1. It could be seen that these pores on the AAO membrane had a uniform size and were arranged in a honeycomb hexagonal structure. The average diameter of pore was about 90 nm and the pore density was 1.05×10^{10} cm⁻². The thickness of porous AAO membrane on the aluminum substrate was about 2 μm. By a conventional scratch test, the critical scratch load of the

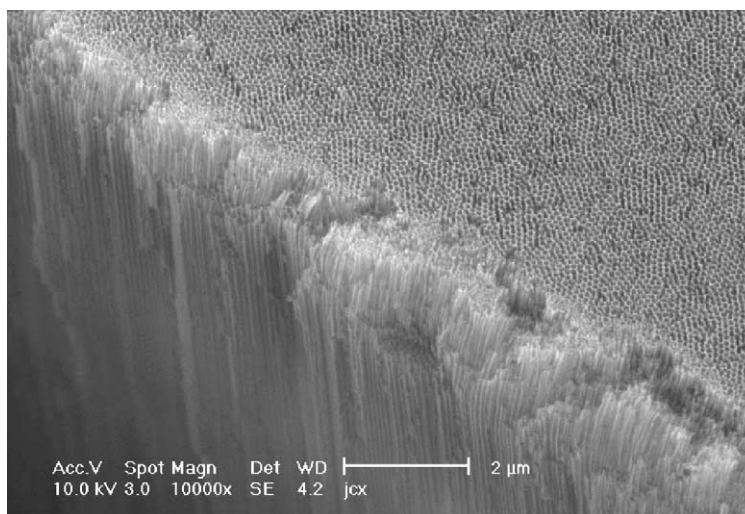


Fig. 1. SEM image of porous AAO membrane.

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