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Enhanced tribological behavior of anodic films containing SiC and PTFE nanoparticles on Ti6Al4V alloy

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ABSTRACT

Anodic films containing SiC and polytetrafluoroethylene (PTFE) nanoparticles were successfully fabricated on Ti6Al4V alloy by using anodic oxidation method in an environmental friendly electrolyte. The morphology, structure and composition of the films were studied with the scanning electron microscope (SEM) and energy dispersive spectrometer (EDS). The results showed that the film contained a layered structure and have a surface full of petaloid bulges, which was totally different from the common anodic oxide film of the porous kind. The tribological properties of the films were investigated with dry friction tests in terms of the friction coefficient, wear rate and the morphology of worn surfaces. The results indicated that the SiC/PTFE composite film exhibited much better anti-wear and anti-friction performances than that of the SiC composite film, the PTFE composite film and the ordinary film without nanoparticles. The SiC/PTFE composite film has friction coefficient of 0.1 and wear rate of 20.133 mg/m, which was decreased respectively by 80% and 44.5% compared with that of the ordinary film. The lubricating mechanisms of the composite film containing SiC and PTFE nanoparticles were discussed. PTFE nanoparticles could lead to the formation of lubricating layer while SiC nanoparticles inside the lubricating layer turned sliding friction to rolling friction.

1. Introduction

Titanium alloys have been widely used in the fields of aeronautics, astronautics, shipping and medical industry due to the excellent performance, such as high specific strength, corrosion resistance and biocompatibility [1,2]. However, the poor tribological properties of titanium alloys have greatly limit their scope of application [3]. Thus titanium alloys coated with oxide films that have good tribological properties are desired.

Anodic oxidation is a traditional surface treatment technology that has been widely applied. This technology has a simple process, and oxide films obtained have excellent performance [4–6]. In recent years, many investigations of composite oxidation films with nanoparticles have been taken on aluminum alloys [7–15]. Some investigations reveal that organic polymer such as PTFE [8–10] and hard ceramic materials such as SiC and ZrO_2 [11–15] can significantly improve the tribological property of oxide films. The reason that composite films containing organic polymer or ceramic nanoparticles shows enhanced tribological property is that organic polymer have a self-lubrication property [16] and ceramic nanoparticles can improve the hardness [17]. However, organic polymer composite films cannot reach high hardness [16] and ceramic nanoparticles also behave as a high friction coefficient and have high surface roughness [8]. Therefore, composite films contain SiC and PTFE nanoparticles are expected to be more attractive on the synergistic effect. In addition, most electrolytes used for anodic oxidation are strong acid and alkali solution [17–19]. With the increasing environmental matters, an environmental friendly electrolyte deserves to be applied.

In this paper, SiC/PTFE composite films on Ti6Al4V alloy were successfully prepared by using anodic oxidation method in an environmental friendly electrolyte. The morphology and structure of oxide films were observed. The tribological properties of SiC/PTFE composite films were deeply investigated compared with SiC composite films and PTFE composite films. Furthermore, the enhancement mechanisms and the synergistic effect of SiC and PTFE nanoparticles working on the tribological properties of composite films have been studied and discussed.

2. Experimental details

2.1. Materials and preparation

The elementary composition of Ti6Al4V alloy is shown in Table 1. A block of titanium alloys was cut into flakes with the size of 10 mm × 10 mm × 2 mm. Before anodic oxidation, samples

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Table 1
Elementary composition of Ti6Al4V alloy (wt%).

Al	V	Fe	C	N	O	Ti
6.32	4.10	0.30	0.10	0.05	0.13	Balance

Table 2
Parameters of anodic oxidation process.

Parameter	Value
Current density ($A\,dm^{-2}$)	5
Anodizing time (min)	50
Temperature (°C)	10 ± 3
Duty ratio	2:8
Frequency (Hz)	1.3

were ground continuously with silicon carbide abrasive papers from 150# to 2000#, cleaned ultrasonically in acetone. Then they were degreased in a mix solution of Na_2SiO_3 (25 g/L) + NaOH (40 g/L) + $NaCO_3$ (25 g/L) + Na_3PO_4 (40 g/L) for 10 min at 50 °C, rinsed with deionized water, and finally air dried.

The anodic oxidation process was conducted by using a home-made DC pulse power. The temperature of electrolyte was kept below 30 °C by using a thermostatic waterbath and a magnetic stirrer during the anodic oxidation process. A stainless steel and the samples were used as the cathode and anode. Experimental conditions of the anodic oxidation are shown in Table 2. The base electrolyte was 30 g/L sodium tartrate ($C_4O_6H_4Na_2$) solution. The PTFE aqueous dispersion used containing 60 wt% PTFE nanoparticles about 250–400 nm in size. And SiC nanoparticles used have a diameter of about 40 nm. Before anodic oxidation, SiC

Table 3
Description of the anodizing electrolytes and nomenclature of the corresponding films.

Films reference	Anodizing electrolytes composition	
	Sodium tartrate	Additives
Ordinary film	30 g/L	
SiC composite film	30 g/L	5 g/L SiC
PTFE composite film	30 g/L	4 ml/L PTFE
SiC/PTFE composite film	30 g/L	5 g/L SiC + 4 ml/L PTFE

nanoparticles were treated by anionic surfactants ($C_{12}H_{25}OSO_3Na$) [20] and ultrasonic dispersion for 1 h [21]. Samples were anodized in four different electrolytes, and the compositions of those are summarized in Table 3.

2.2. Morphology and phase composition

Surface and cross-section morphologies of the coating were observed with a scanning electron microscope (SEM, HitachiS-4800). The energy dispersive spectrometer (EDS) was used to measure the elementary composition of the composite films.

2.3. Tribological test

The tribological test was performed using a ball-on-disc rotating wear tester (UMT-2, America). A Si_3N_4 ceramic ball with a diameter of 2 mm and surface roughness about 0.01 μm was used as the counterpart. All the tests were performed at a load of 400 g with a rotation diameter of 4 mm and rotating velocity of 100 rpm in ambient air of normal humidity under dry conditions at room

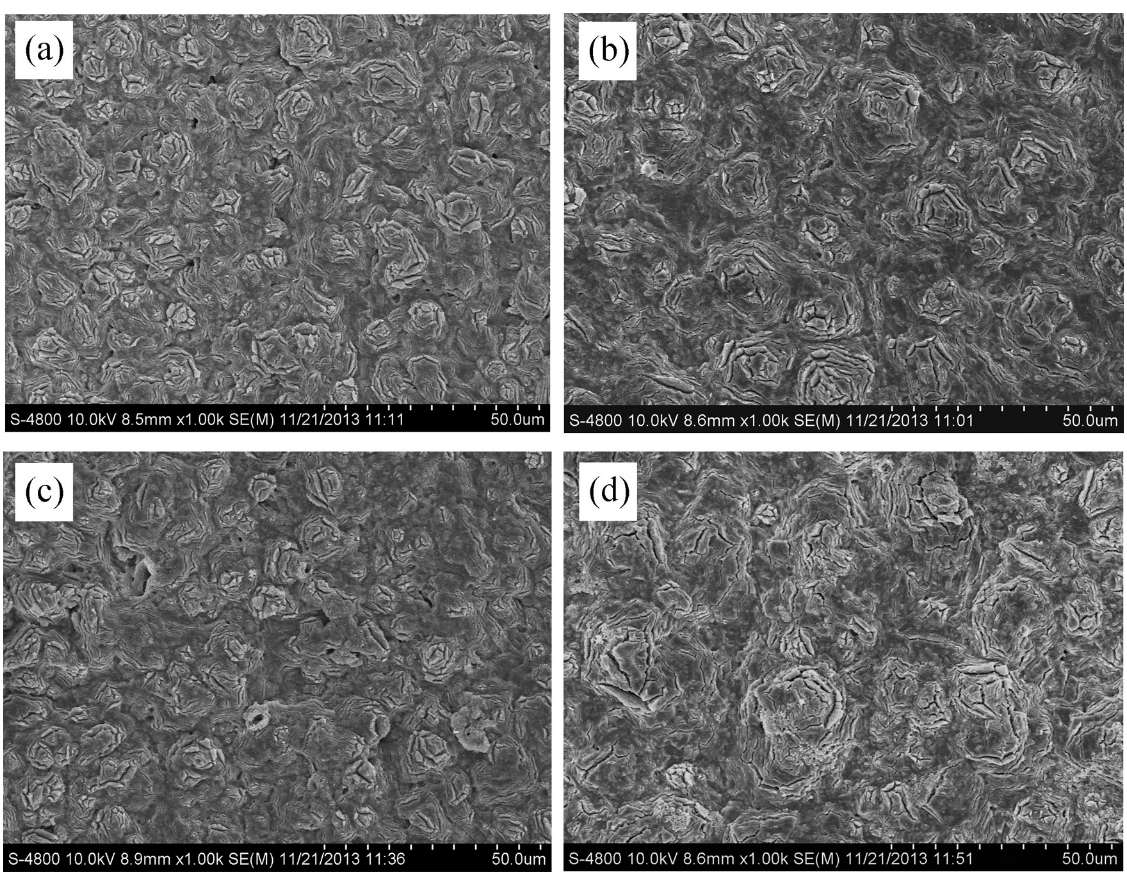

Fig. 1. Low magnification SEM images of the oxide films formed in the sodium tartrate electrolyte (a) without nanoparticles, (b) with SiC nanoparticles, (c) with PTFE dispersion and (d) with SiC nanoparticles and PTFE dispersion.