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Jet pulse electrodeposition and characterization of Ni–AlN nanocoatings in presence of ultrasound

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ABSTRACT

In current study, Ni–AlN nanocoatings were successfully prepared by adopting the jet pulse electrodeposition (JPE) technique with ultrasound. The scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), Vickers microhardness test, electrochemical workstation and friction wear tests were utilized to investigate the microstructure, mechanical properties, corrosion degree and wear resistance of the coatings. The results indicated that the Ni–AlN nanocoatings deposited by using ultrasound demonstrated the minimum and most compact surface structure compared to the other coatings. The thicknesses of Ni coating and Ni–AlN nanocoatings were approximately 56 μm. The average atomic percent of Al and Ni elements in the Ni–AlN nanocoating prepared by using ultrasound, were approximately 21.4 at% and 47.5 at%, respectively. The maximum kinetic energy of the jet plating solution was 916 m^2/s^2 during JPE-deposited Ni-AlN nanocoatings including ultrasound. The average micro-hardness value of the nano-coating prepared by using ultrasound equaled 767.9 HV. The Ni–AlN nanocoatings prepared using ultrasound had the minimum E_{corr} and I_{corr} values of − 0.167 V and 6.363 × 10^{-6} mA/cm^2, respectively. In this case, the demonstrated corrosion resistance was the most efficient. The Ni–AlN nanocoatings prepared using ultrasound sustained the minimum friction coefficients and the average friction coefficient was approximately 0.52. In contrast, the JPE-deposited Ni coating presented the maximum friction coefficient, while the average friction coefficient was approximately 1.43.

1. Introduction

Pulse electrodeposition (PE) of metal matrix coatings containing ceramic particles (such as AlN, TiN, diamond, Al_2O_3), has been ordinarily utilized to enhance the micro hardness, modulus of elasticity, wear resistance, as well as corrosion property of metal parts, relative to those of pure metallic membranes [1–4]. The PE-deposited coatings with excellent mechanical, tribological and non-corrosive properties can expand the lifetime of metal components exposed to high temperature, heavy loads and corrosive environments, since most of failures (e.g. oxidation, friction, wear and corrosion, etc.) in these conditions often occur on the material surface. Recent literature on the PE technique of metal matrix coatings is under consideration globally. Ma et al. [5], demonstrated that Ni-TiN thin films with different TiN nanoparticle contents were fabricated from a nickel bath with the addition of TiN nanoparticles loadings. It was demonstrated that the film deposited at 2 g/L presented a (2 0 0) preferred orientation. However, as long as the TiN additive concentration increased from 2 g/L to 6 g/L, the (2 0 0) preferred orientation was suppressed and a random orientation occurred. Li et al. [6], reported the preparation of Ni–TiN nano-composite coatings through pulse electroplating utilization, from a Watts type nickel plating bath. Dehgahi et al. [7], presented Ni–Al_2O_3–SiC nanocoatings prepared through PE. Gyawali et al. [8], electrodeposited Ni-SiC composite coatings on SUS304 stainless steel substrates and observed that in samples subjected to ultrasound, nanoparticles obtained with homogeneous distribution and reduced agglomeration, indicated significant improvements in micro-hardness and wear resistance of the composite coatings, compared to the coatings deposited in samples without ultrasound.

Jet pulse electrodeposition (JPE) corresponds to an electrodeposition method that utilizes a circulating pump to inject with a certain pressure an electroplating solution on the cathode surface, for metal matrix coatings preparation. Due to the characteristics of low-cost, high-efficiency and simple superiorities, JPE technique has emerged as the center of attraction of widespread research worldwide. Xia et al. [9], revealed that Ni-TiN thin films could be synthesized by JPE method. The results indicated that the depths of the Ni-TiN thin films deposited at 3, 5 and 8 g/L, corresponded approximately to 35, 28 and 30 μm, respectively. Tian et al. [10], indicated that nano-crystalline nickel coatings could be fabricated by JPE on the substrate of 45 carbon

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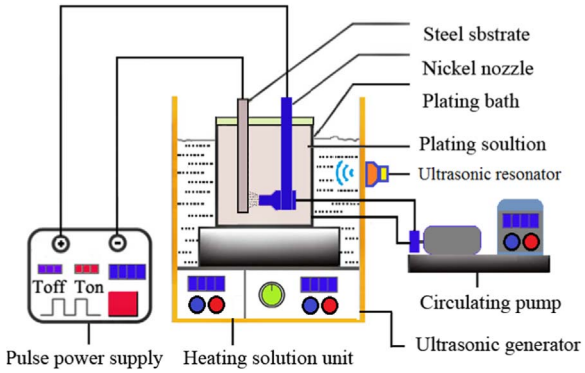

Fig. 1. Experimental diagram for depositing Ni–AlN nanocoatings.

steel. Zhuo et al. [11], reported that the nickel coatings were successfully prepared by using the JPE. The results revealed that the contact pressure between the flexible friction medium and the coating had an significant effect on the coating properties.

AlN, acclaimed as a metal nitride ceramic material, has been widely applied in opto-electronics, semiconductor manufacturing and military applications due to its fine physical and chemical properties [12–14]. Co-deposition of micro- or nano-sized AlN particles in metal matrix has been extensively reported in research during the last decade. Xia et al. [15], electrodeposited Ni–AlN composite coating on the surface of steel substrates by using pulse electroplating technique. Gu et al. [16], discussed the prefabrication of Cu/AlN nano-composites of increased strength and conductivity. It was demonstrated that the hardness of the Cu/AlN nano-composite raised by increasing the repressing pressure and AlN particle content.

The present study has as a scope to adopt the JPE method in the preparation of Ni–AlN nanocoatings with ultrasound and to compare the microstructures, micro-hardness, wear and corrosion resistances of nickel coating and Ni–AlN nanocoatings prepared without ultrasound. The following techniques were utilized to investigate the effect of different plating method on the microstructure, mechanical properties, corrosion degree and wear resistances of the coatings: scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), Vickers micro hardness test, electrochemical workstation and friction wear test.

2. Experimental

2.1. Preparation of Ni–AlN nanocoatings

In current research, Ni–AlN nanocoatings were deposited through JPE techniques in a jet electrodeposition system (Fig. 1). The system consisted of a pulse power supply, a heating solution unit, an ultrasonic generator, a circulating pump and a nickel nozzle. The pulse power supply (SMD-60) generated a pulse current for Ni-AlN nanocoatings

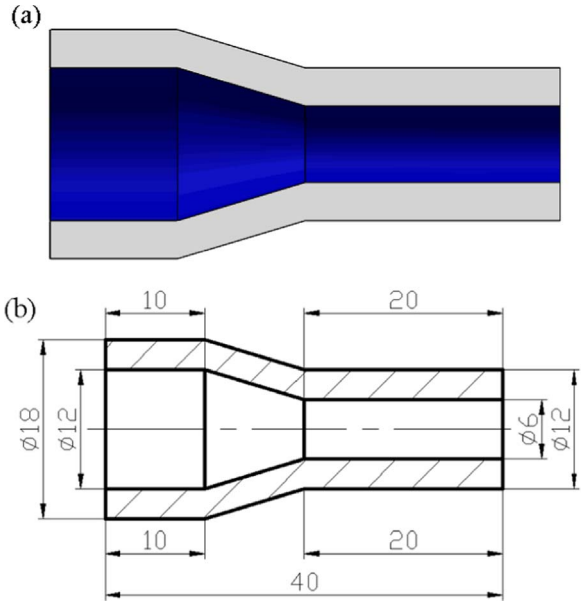

Fig. 2. The structure and geometrical dimension of the nickel nozzle: (a) 3D structure, and (b) Geometrical dimension.

preparation and the current density was set at 6 A/dm^2. The heating solution unit (HT-2000) was utilized to keep the plating bath temperature at 48 °C. The ultrasonic generator (XL-400) was applied to generate the ultrasonic frequency (40 kHz) and corresponding power (30 W/cm^2). Through a circulation pump (type 10CQ-3), the plating solution in the plating bath was jetted onto the surface of the cathode, including a jet rate of 4 m/s. The cathode consisted of A3 steel substrate (50 mm × 30 mm × 8 mm). AlN nanoparticles (Shanghai Nanoceramic Technology Co., Ltd., PR China) presented an average particle size of 25 nm. The plating bath composition and operating conditions are listed in Table 1. The nickel nozzle was applied to control the jet plating parameters during the preparation of Ni–AlN nanocoatings, while the structure and geometrical dimension of the nozzle is illustrated in Fig. 2. The distance between the nickel nozzle and substrate was set at 20 mm.

2.2. Characterization of Ni–AlN nanocoatings

The microstructures and cross-sectional distributions of the Ni–AlN nanocoatings were evaluated by using SEM (JSM-6400) and XPS (Vg-Escalab-200iXL), respectively. The micro-hardness value of the nanocoating was investigated through a HVS-1000D model Vickers microhardness tester (Changzhou Sanfeng Microhardness Tester Co., Ltd., PR China) along the profile of the coating, at an interval of 10 μm. The actual applied load on the surface of the coating was 0.49 N, while the loading period was 20 s.

Table 1
Plating bath composition and operating conditions for fabricating Ni–AlN nanocoatings.

Sample	Ni coating (denoted as JPE-1)	Ni-AlN nanocoating (denoted as JPE-2)	Ni-AlN nanocoating (denoted as JPE-3-US)
$NiSO_4$ (g/l)	260	260	260
$NiCl_2$ (g/l)	30	30	30
H_3BO_3 (g/l)	20	20	20
AlN nanoparticles (g/l)	0	6	6
Cetyltrimethyl ammonium bromide (mg/l)	60	60	60
Plating temperature (°C)	48	48	48
Current density (A/dm^2)	6	6	6
Duty cycle (%)	20	20	20
pH	4.5	4.5	4.5
Ultrasonic frequency (kHz)	0	0	40
Ultrasonic power (W/cm^2)	0	0	30
Plating time (min)	80	80	80