



Effects of bivalent Co ion on the co-deposition of nickel and nano-diamond particles

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Abstract

Nano-diamond particles were co-deposited on AISI-1045 steel substrates with nickel from a Watts-type bath by conventional electrodeposition methods. The effects of Co^{2+} additives on the co-deposition of nano-diamond particles, the surface morphology, microhardness, surface roughness and tribological properties of nanocomposite coatings were investigated. Results in this paper showed that the addition of Co^{2+} in the Ni/diamond plating bath significantly improved the amount and uniformity of dispersed nano-diamond particles in the metal matrix. Moreover, it has been established that the nanocomposites obtained with the addition of Co^{2+} in the Ni/diamond plating bath produced much higher hardness and excellent anti-wear performance with lower friction coefficient when sliding against a steel ball. It has been assumed that Co^{2+} may act as a cationic stimulator, which promoted the co-deposition of nano-diamond particles with nickel and thus intensified the positive contribution of the embedded nano-diamond particles.

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1. Introduction

Electrodeposited composite coatings have been widely developed over the past decades for various engineering applications due to the interesting possibilities it offers. Many researches have focused on the co-deposition of micro-sized particles such as metallic powder, silicon carbides, oxides, polymer and diamond, etc. [1–7]. By combining the properties of heterogeneous matrix metal and various kinds of particles, many new function materials were created with more comprehensive applications. However, the co-deposition of metal matrix with these micro-sized particles led to poor dispersion of particles in suspension, bad surface quality and weak bonding strength between matrix and particles [3]. Several studies have found that the co-deposition of nano-sized or submicron particles with metal matrixes is superior to micro-sized particles on qualities of the composite coatings. Among these ultra fine particles, ultradispersed diamond particles

are increasingly attracting considerable scientific and technological interest by virtue of their unique mechanical and tribological properties including higher hardness, lower friction coefficient and inertness to chemical attack. But recent researches have proved that these nano-sized particles are more difficult to be co-deposited with metal than coarse particles [2–5]. Hence, how to improve the co-deposition content of these nano-sized particles has attracted much attention recently.

Since the particle surface state is of great importance to the co-deposition process, it has been widely supposed that the above problem can be overcome significantly by the surface modification of these particles [8,9]. More probably, surface modification can be achieved through organic surface-active additives; Attempts to increase the incorporation of the co-deposited particles using various organic surfactants in the electrolyte have been reported by many researchers [5,8,9]. On the other hand, inorganic additives for modification of the particle surface state are much more important and practical, since the addition of organic additives can cause such disadvantages as instability in the electrolyte, high stress or brittleness of the composite deposits, etc. Unfortunately, few studies have concentrated

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on effects of inorganic additives on the co-deposition process at present.

In the present work, the Ni-based nanocomposites were deposited on AISI-1045 steel substrates by electroplating. The effects of Co^{2+} on the co-deposition of nano-diamond particles with nickel were investigated by evaluating the microstructure, microhardness, surface roughness and tribological properties of the nanocomposite coatings.

2. Experimental

The nickel and nano-diamond particles were electro-deposited on the steel substrates from modified Watts-type bath. The nano-diamond particles used in the experiments were in spherical or spherical-like shapes and had an average size of 3–10 nm obtained by explosive detonation, as shown in Fig. 1 [10]. Prior to the co-deposition, the diamond particles were ultrasonically dispersed in the bath for 10 min. The basic compositions of the electrolyte and plating conditions are shown in Table 1. Each experiment was carried out with a fresh solution.

AISI-1045 steel plates were used as cathodes, the anode was a pure Ni plate. Before the co-deposition, the substrates were mechanically polished to a 0.08–0.12 μm surface finish, then a sequence of cleanings were performed to remove contamination on the substrate surface, the steel substrates were activated for 20 s in a mixed acidic bath. During the co-deposition process, the bath was slowly stirred by a magnetic stirrer in order to keep the particle well dispersed and prevents them from sedimentation in the bulk of electrolyte-suspension. The temperature of the electrolyte was maintained at a set value by an automatic controller. The pH value of the electrolyte was adjusted by H_2SO_4 or $\text{NH}_3\cdot\text{H}_2\text{O}$. The thickness of the coatings were fixed to 25 μm .

The surface morphology and microstructure of the coatings were investigated using a JSM-5600 Lv scanning electron microscopy (SEM) equipped with Kevex sigma™ energy dispersive X-ray spectroscopy (EDS) analysis tool.

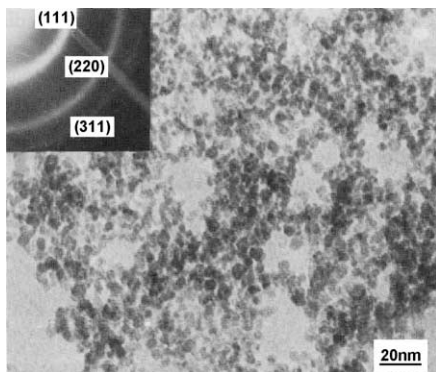


Fig. 1. TEM image of nano-diamond particles obtained by explosive detonation.

Table 1

Basic bath compositions and plating conditions

Compositions and conditions	
Nickel sulfate, $\text{NiSO}_4\cdot 6\text{H}_2\text{O}$ (g/l)	300
Nickel chloride, $\text{NiCl}_2\cdot 6\text{H}_2\text{O}$ (g/l)	50
Boric acid, H_3BO_3 (g/l)	40
Additive brightener A (g/l)	0.5
Nano-diamond content (g/l)	10
Temperature ($^\circ\text{C}$)	45
pH	3–5
Current density (A/dm^2)	1–5
Stirring speed (rpm)	100–500

A surface profilometer was employed to measure the surface roughness. Microhardness of the coatings was determined using a Vicker's microhardness indenter with a load of 25 g for 5 s, for the selected load, the substrate effects on hardness can be avoided, the final value quoted for the hardness of a deposit was the average of 10 measurements.

The tribological behavior was tested on a reciprocating ball-on-disk UMT-2MT tribometer at room temperature with a relative humidity of 45–55% under dry sliding conditions. A AISI-52100 stainless steel ball (diameter 4 mm with hardness of RC 62) was used as the counter body; all tests were performed under a load of 1 N with a sliding speed of 65 mm s^{-1} . The friction coefficient and sliding time were recorded automatically during the test. The wear volume was measured using a surface profilometer, the wear rates of all coatings were calculated using the equation of $K = V/SF$, where V is the wear volume in mm^3 , S is the total sliding distance in m and F is the normal load in N.

3. Results and discussion

3.1. Effect of Co^{2+} on co-deposition and mechanical properties of coatings

Ni/diamond composites were deposited under a current density of 1.5 A dm^{-2} and a pH of 4.2, while Ni-Co/diamond composite coatings were obtained with 2.5 g dm^{-3} Co^{2+} in the Ni/diamond plating bath under the above mentioned plating conditions. The comparative hardness results of composites and pure nickel (including Ni-Co) coatings are shown in Fig. 2. Ni/diamond and Ni-Co/diamond composites exhibited much higher hardness as compared to the Ni and Ni-Co coatings, which is linked with the dispersion hardening effect caused by the incorporation of nano-diamond particles in the metal matrix. Moreover, the Ni-Co/diamond composite coating showed the highest microhardness. It is well known that the hardness and other mechanical properties of metal matrix composites depend on the amount of the dispersed phase and the mechanical characteristics of the matrix [11]. For the above two matrixes, the hardness value of the Ni-Co matrix is slightly higher than that of a Ni matrix. However, with the