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Effect of electrodeposition conditions on structure and mechanical properties of Ni-W/diamond composite coatings

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ABSTRACT

Ni-W/diamond composite coatings were prepared by electrodeposition from a Ni-W plating bath with diamond particles suspended into the bath. The effect of the plating parameters on microstructure and mechanical properties was investigated. The deposits reported a maximum hardness of 1207 ± 32 *Hv*. The film hardness is depended on the concentration of diamond particles in the plating bath and also on the size of the co-deposited diamond particles. The sample with diamond concentration of 10 g/L in the bath and co-deposited at current density of 0.15 A/cm^2 reported the optimized wear resistance and diamond content in the deposit. In this paper the effect of the incorporation of diamond particles into the Ni-W matrix has been discussed in terms of the aforesaid operating conditions and particle size.

1. Introduction

Composite electrodeposition is a suitable technique of co-depositing various particles of pure metals, ceramics and organic materials in a base matrix of metal/metal alloys to improve the deposits properties such as hardness, wear resistance, surface roughness and uniformity of distribution of co-deposited particles [1–10]. Hardness is an important surface property which relates to the wear resistance and mechanical strength of the material. Hard coatings are used to improve the longevity of products, facilitate the enhancement of performance for cutting tools and other materials which are coated with hard materials such as diamond by various wet and dry processes. However, there are various advantages of wet process of fabrication of coatings over the dry process which involves the use of costly equipment, extreme reaction conditions and higher costs. Electrodeposition is a simple and very commonly used method of wet process deposition of films. It is extensively used to fabricate hard metal and alloy films on materials (for example Cr, Ni-W alloy) [11–14] to name a few.

Electrodeposited Ni-W alloy coatings have been able to serve as a replacement to the hazardous hexavalent chromium coatings [15–17]. Various researchers report that the hardness of the Ni-W alloy is mainly determined by the W content and grain size of the electrodeposited Ni-W [18–21]. The hardness of the as-deposited Ni-W alloy has been reported to vary between 460 and 670 *Hv* [18–21]. However, the hardness of the Ni-W alloy is significantly lesser than that of chromium coatings which report high hardness of 1100 *Hv* [20,22]. Moreover, various literatures have stated that addition of suitable particles (for example diamond, Al_2O_3, WC and SiC) to a hard alloy matrix can significantly enhance mechanical properties such as hardness, wear resistance and corrosion resistance of the deposits [17,23–26]. However, for composite coatings of nanostructured Ni-W matrix reinforced by diamond particles there are only a few publications. Hou et al. [27] prepared Ni-W/diamond composite coatings and investigated it's mechanical properties. They reported that the highest level of incorporation of diamond was about 21.1 vol.% at diamond concentration in bath of 1 g/L. In our previous study, Ni-W/diamond composite coatings were also deposited by pulse electrodeposition [10] and sediment co-electrodeposition method [28]. The results demonstrated that the pulse current can affect the diamond incorporation and W content in the deposit. Further, the sediment co-electrodeposition method could significantly improve the diamond content in deposits, resulting high hardness of Ni-W/diamond composite coating. Combined with previous research on Ni-W/diamond [10,27–29], Ni/diamond [3,6], Ni-Co/diamond [2,7], Ni-P/diamond [1,5,30], Ni-B/diamond [4] composite coatings, the electrodeposition parameters and size of diamond particles can strongly affect the properties of composite coating. Therefore, this paper aims to further investigate and

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examine the effect of electrodeposition conditions on microstructure and mechanical properties for the Ni-W/diamond composite coating.

In the present study, co-deposition of Ni-W/diamond composite coating was prepared from Ni-W plating bath containing diamond particles in suspension. The effect of electrodeposition parameters on the hardness, wear resistance and microstructure of the deposits were investigated. Microstructural and mechanical properties of the obtained Ni-W/diamond composite coatings that were directly related to the electrodeposition conditions were also determined.

2. Experimental details

Ni-W/diamond composites were fabricated by means of electrodeposition from an ammonia-citrate bath (200 mL). The bath composition was nickel sulphate 18 g/L, sodium tungstate 53 g/L, tri-sodium citrate 168 g/L, ammonium chloride 31 g/L, sodium bromide 18 g/L. The deposition was carried out The diamond concentration was varied in the bath (1 g/L, 2 g/L, 3 g/L, 5 g/L, 10 g/L and 20 g/L) and the particle size of diamond used were 0.2, 0.3, 0.9, 3 and 6 μm, respectively. The operating temperature was 75 °C. The pH, stirring speed and the deposition time was kept constant at 8.9, 200 RPM and 2 h, respectively. The current density was varied between 0.05 and 0.2 A/cm^2.

During the electrodeposition process, Pt mesh was applied as anode, and carbon steel was used as a cathode, and the distance was 35 mm. The coating area was fixed at 2*2 cm^2. The substrate was rinsed with soap solution before deposition and pre-treated with 10% NaOH and 14% HCl solution for a period of 20 and 10 min, respectively. Prior to insertion of the electrodes in the plating bath, the substrate was activated by 14% HCl. Except the deposition area the other undesirable parts of the substrate was covered with polymer tape.

X-Ray diffraction (XRD) technique was employed to analyze the phases of the deposits along identification and analysis of the crystalline structure of the coatings. Brooker D8 advance X-ray diffractometer operated at Cu Kα radiation at a rating of 40 kV, 20 mA. The scan rate was 0.02° per step and the measuring time 0.5 s/step. Scherer's equation [27] was employed for the calculation of the grain size of the electrodeposited coatings.

$$D = \frac{0.9\lambda}{\beta \cos\theta} \quad (1)$$

where, D is the grain size, λ is the X-ray wavelength (1.5418 Å), β is the corrected peak width at half maximum intensity (FWHM) and θ is Bragg angle.

The samples were characterized in terms of morphology and microstructure by JEOL JSM-6400 scanning electron microscope (SEM) with energy dispersive X-ray spectroscopy (EDS) capability embedded into it. The volume percentages of the incorporated diamond particles in the obtained Ni-W/diamond composite coatings were determined from the cross-sectional SEM images by the image analysis software (ImageJ) to estimate the portion of diamond content in the coatings.

The coating hardness was measured on the surface using Mitutoyo hardness tester with a Vickers's diamond indenter under a load of 100 g (0.98 N) at seven different locations of the coating. The dwell time for each indentation was 15 s. The Vickers hardness can be calculated in accordance with the formula:

$$Hv = 1854\frac{L}{d^2} \quad (2)$$

Here, *Hv* is the hardness in Vickers's and L. is the applied load and *d* is the diagonal of the indentation. The average value of the five measurements (except the maximum and minimum values) is quoted here as the hardness of the obtained composite coating.

The tribological property of the deposits was analyzed by wear test. The wear test was carried out at an air humidity of 45 ± 10 RH% and a temperature of 24 ± 1 °C using a ball-on-disc tribometer with the sample placed horizontally on a turntable. The tests were performed by applying a load of 20 N to a zirconium dioxide ball of diameter 6 mm, a linear speed of 9.42 cm/s for a total sliding distance of 500 m and for the total wear duration of 53 min. The hardness of the zirconium dioxide ball was ~1300 *Hv*. Before each test, both the sample and the ball counter face were ultrasonically cleaned in acetone for 10 min, and dried by hot air. The anti-wear performance of the films was estimated from the weight loss of the specimens.

3. Results and discussion

Fig. 1 (a–d) shows the SEM image of Ni-W/diamond (NWD) composite deposits fabricated at 1 g/L, 3 g/L, 5 g/L and 10 g/L diamond concentration in plating bath at current density of 0.15 A/cm^2, respectively. 3 μm diamond particles were used for the fabrication of NWD deposits at 0.15 A/cm^2 and varying diamond concentration in the plating bath. Fewer diamond particles appear to be co-deposited on the surface for samples fabricated at 1 g/L (Fig. 1 (a)) and 3 g/L (Fig. 1 (b)) diamond concentration in the plating bath. Upon increasing the plating bath diamond concentration to 5 g/L (Fig. 1 (c)) and 10 g/L (Fig. 1 (d)) the

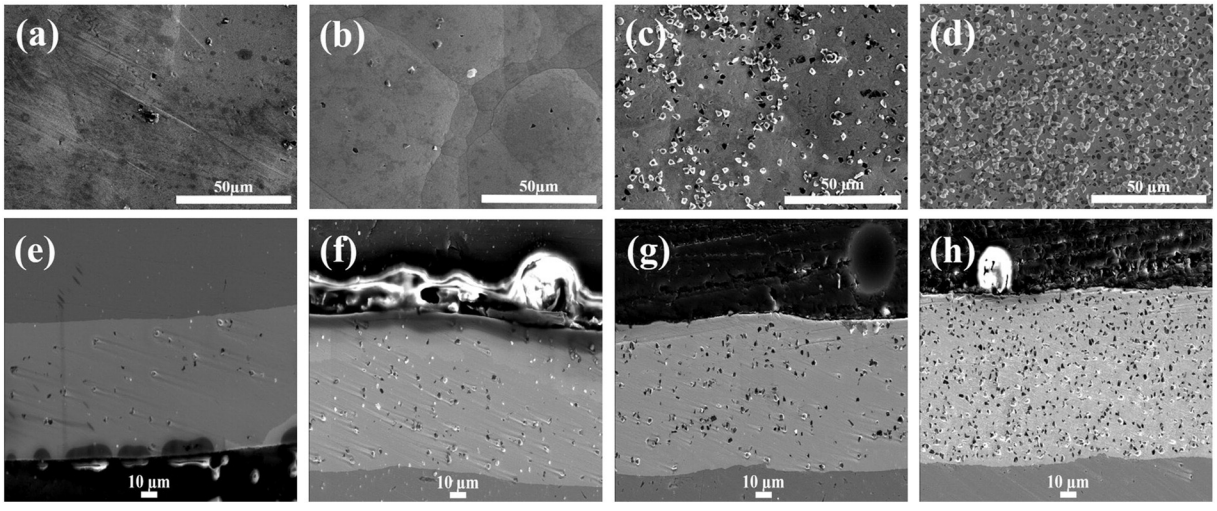

Fig. 1. Effect of diamond concentration in plating solution on morphology of Ni-W/diamond composite coatings prepared at temperature of 75 °C, pH 8.9, and current density of 0.15 A/cm^2, SEM images, (a) 1 g/L, (b) 3 g/L, (c) 5 g/L, (d) 10 g/L, and cross section SEM images, (e) 1 g/L, (f) 3 g/L, (g) 5 g/L, (h) 10 g/L.