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# Microstructure and tribological properties of electrodeposited Ni–Co alloy deposits

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## Abstract

Ni–Co alloys with different compositions and microstructures were produced by electrodeposition. The effects of Co content on the composition, surface morphology, phase structure, hardness and tribological properties of Ni–Co alloys were investigated systemically. Results showed that the morphology and grain size of alloys are mainly influenced by the Co content and the phase structure of Ni–Co alloys gradually changed from fcc into hcp structure with the increase of Co content. The hardness of Ni–Co alloys with a maximum around 49 wt.% Co followed the Hall–Petch effect. It was found that the improvement of wear resistance of Ni-rich alloys with hardness increase fits Archard's law. In addition, the Co-rich alloys exhibited much lower friction coefficient and higher wear resistance when compared with Ni-rich alloys. It has been concluded that hcp crystal structure in Co-rich alloys contributed to the remarkable friction–reduction effect and better anti-wear performance under the dry sliding wear conditions.

*Keywords:* Ni–Co alloy; Electrodeposition; Structure; Tribological properties

## 1. Introduction

Ni–Co alloys have been investigated as important engineering materials for several decades because of their unique properties, such as high-strength, good wear resistance, heat-conductive, electrocatalytic activity [1–5]. Additionally, the use of Ni–Co alloys has been extended to the production of three-dimensional, complex-shaped finished components by the electroforming technique [6,7]. The investigations on the electrodeposited Ni–Co alloys have shown that their microstructure and properties were found to depend strongly on the Co content, which can be controlled by the experimental parameters, such as bath composition, temperature, pH value, and current density, etc. [1,3,8]. The effects of plating parameters

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on the composition and morphology of Ni–Co deposits were compared in many literatures [4,5,9]. Golodnitsky et al. recently studies the effects of Co content on the tensile strength, internal stress and high-temperature oxidation of Ni–Co alloys [3]. Their activities for the oxygen evolution reaction and hydrogen evolution reaction were also studied on electrodeposited Ni–Co ultramicroelectrodes [10,11]. Moreover, much interest is focused on the magnetic properties of Ni–Co alloys due to the application of these alloys in various magnetic devices, especially in microsystem technology for manufacture of sensors, actuators and inductors [12,13]. It is reported that the magnetic properties of Ni–Co alloy are greatly influenced by the composition and phase structure of Ni–Co alloy [14]. Unfortunately, there are very limited studies focused on the friction and wear properties of Ni–Co alloys as a function of their microstructure and composition.

In the present paper, Ni–Co alloys with different Co content were electrodeposited on AISI-1045 steel substrates. The composition, microstructure, mechanical, and tribological properties of Ni–Co alloys were compared systemically in order to specifically correlate the structure and tribological properties of Ni–Co alloys.

## 2. Experimental

Ni–Co alloys were electrodeposited from a typical Watts-type electrolyte, containing Nickel sulfate (200 g/l), sodium chloride (20 g/l), boric-acid (30 g/l), sodium lauryl sulfate (0.1 g/l) and cobalt sulfate (0–80 g/l). In addition, pure Ni was also produced for comparison purpose. The Ni–Co alloys were deposited on AISI-1045 steel substrates by choosing a current density of 3 A/dm$^2$ at a bath temperature of 45 °C. The anode was a pure Ni plate. The pH of the bath was kept at 4.0 adjusted by ammonia water or dilute sulfuric-acid. Before deposition, the substrates were mechanically polished to a 0.10–0.12 μm surface finish, the substrate was then degreased in acetone with ultrasonic cleaning for 5 min, rinsed in the running water to remove contamination on the substrate surface. After than, the steel substrates were activated for 20 s in the 20 vol.% HCl solution, and finally rinsed with distilled water.

The surface morphology and microstructure of the alloy deposits were investigated using a JSM-5600Lv scanning electron microscopy (SEM). The compositions of Ni–Co alloys were determined with energy dispersive X-ray spectroscopy (EDS) analysis tool attached to SEM. The crystal structure and phase composition of alloy deposits were studied by X-ray diffraction (XRD). Microhardness of the deposits was determined using a Vicker's microhardness indenter with a load of 50 g for 10 s, indentations were made on the 50 μm thick deposits. 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 (Center for tribology, Inc., California, USA) at room temperature with a relative humidity of 45–55% under dry sliding conditions. 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 3 N with a sliding speed of 55 mm s$^{-1}$. The friction coefficient and sliding time were recorded automatically during the test. The wear volume loss was measured using a surface profilometer, wear rates of all the alloy deposits were calculated using the equation of $K = V/SF$, where $V$ is the wear volume loss in mm$^3$, $S$ the total sliding distance in m and $F$ the normal load in N.

## 3. Results and discussion

### 3.1. Composition of Ni–Co alloys

The dependence of the composition of Ni–Co alloys on the concentration of Co$^{2+}$ ions in the electrolyte at a fixed concentration of Ni$^{2+}$ ions is presented in Fig. 1. It is clearly observed that the Co content in alloy deposits increased gradually with the increase of Co$^{2+}$ concentration in the electrolyte. Note that the percentage of Co in the alloys was always higher than in the electrolyte in agreement with [3,5], which is confirmed by the anomalous codeposition of Ni–Co alloy. Namely, the less noble metal (Co) is preferentially deposited. A generally accepted explanation for these anomalous phenomena was the change of the near-electrode pH, the formation of metal hydroxyl and their competitive adsorption [15,16].