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Effect of Current Density on Properties of $Ni\text{-}Cu/Al_2O_3$ Composite Coatings

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1. Introduction

The coatings can protect the surface of the engineering components against corrosion, fatigue and fracture phenomena. Metallic coatings have produced for these aims. Incorporation of ceramic particles such as Al_2O_3, SiC, SiO_2, TiO_2, in metallic coatings increases mechanical and corrosion properties of the coatings. Metal matrix composite coatings are produced by thermal spraying, chemical vapor deposition (CVD), and electrodeposition techniques. Among these techniques, electrodeposition is one of beneficial techniques for preparing metal matrix composite coatings. The properties of electrodeposited coatings by this process depend on bath composition, electrolyte pH, electrolyte temperature, and current density or deposition potential. Among these parameters, the current density is more effective on electrodeposition rate, coating composition, and properties of the produced coatings. The aim of this research is to examine the current density effect on microstructure, microhardness, and corrosion properties of the $Ni\text{-}Cu/Al_2O_3$ nano-composite coatings, produced by electrodeposition.

2. Experimental procedure

In this research, $Ni\text{-}Cu/Al_2O_3$ nano-composite coatings were prepared from a citrate bath by electrodeposition process. The composition of the deposition bath and electroplating parameters are shown in Table 1.

Table 1. Electrodeposition bath composition and conditions

Bath composition	Concentration (g/L)	Electrodeposition conditions	Value
Nickel Sulfate	320	Current density (A/dm2)	1, 2, 3, 4
Copper Sulfate	40	Rotating speed (rpm)	240
Trisodium citrate	50	Temperature (ºC)	35
SDS	0.2	pH	4.5
Al2O3	20	Deposition time (min)	90

The surface morphology of the produced coatings was examined, using a scanning electron microscope (SEM, TESCAN model). The chemical composition of coatings was examined by energy dispersive X-ray spectroscopy (EDS) attached to SEM. The EDS analysis was carried out over three uniform regions each coating. The Vickers micro-hardness of the elctrodeposited coatings was measured on the cross section of the samples by KoopaMA3 device. The applied load and holding time were 50 g and 10 s, respectively. The corrosion behavior of the nanocomposite coatings were investigated in a conventional three-electrode cell with a platinum plate as the auxiliary electrode and Ag/AgCl as the reference electrode. The measurements were conducted in a 3.5 wt. % NaCl solution at 25 ◦C, using a potentiostat/galvanostat device (Vertex, Ivium Technologies).

3. Results and discussion

Figure 1 shows the effect of current density on chemical composition of the deposited $Ni\text{-}Cu/Al_2O_3$ nano-composite coatings. As it can be seen, by increasing the current density, the Cu decreases and the Ni increases. It has been reported that in citrate-containing electrolytic solutions, nickel deposition is charge-transfer-controlled whereas that of copper deposition is mass-transfer-controlled. Therefore, by increasing the current density charge transfer increase and Ni is increased. On the other hand, by increasing Ni, the concentration of electroactive Cu species at the electrolyte/working-electrode interface becomes depleted, thus Cu decreases in the coating [6, 8, 10].

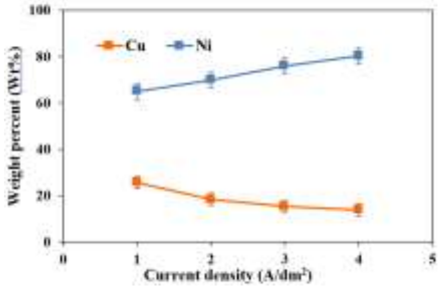

Fig. 1. Composition of matrix versus current density

Figure 2shows the effect of current density on Al_2O_3 nanoparticles content in the deposited $Ni\text{-}Cu/Al_2O_3$ nano-composite coatings. It can be seen that the content of Al_2O_3 in the coatings increases with the increasing of current density up to 2 A/dm^2, while it decreases again beyond the current density. When electrodeposition was carried out at low current densities, nickel ions dissolved from the anode (nickel plate) moved slowly and there is not enough time for these ions to adsorb on particles. Thus, the Coulomb force between nanoparticles and the cathode become weak, which causes lower concentration of Al_2O_3 nanoparticles in the coatings. On the other hand, when the current density is higher than the optimum value, nickel ions dissolve from the anode plate, move faster than the Al_2O_3 particles transported by the mechanical agitation and causes a low concentration of codeposited Al_2O_3 nanoparticles in the coatings.

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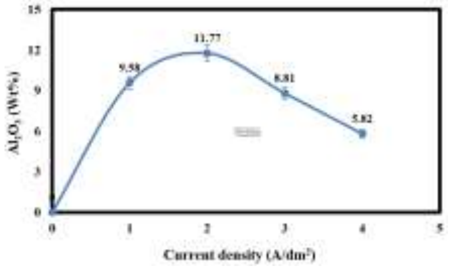

Fig. 2. The content of Al_2O_3 in coatings versus current density

Figure 3 shows the surface morphology of the deposited Ni-Cu/Al_2O_3 nano-composite coatings with the different current density. As it can be seen, by increasing the current density, the morphology of the coatings change from smooth surface to a rough with coarse grains. The presence of the reinforcement particles in the cathode increases its surface. Since the current density around the particles is more than other places, Ni ions deposit around the particles and the protruding grains are created on the surface. This results in a rough morphology. By increasing the current density, the movement of the Ni ions increases and the roughness increases.

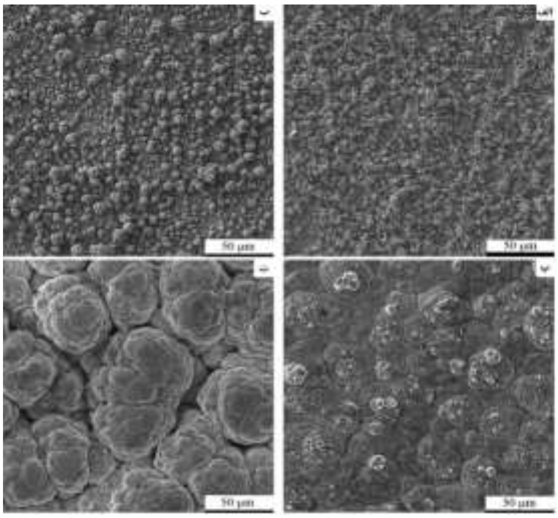

Fig. 3. SEM morphology of the cross section of the coatings in various current densities.

The microhardness of the deposited Ni-Cu/Al_2O_3 nano-composite coatings in various current densities is shown in Figure 4. It can be seen that the microhardness of the coatings increases with the increasing of current density up to 2 A/dm^2, while it decreases again beyond the current density. As is seen in Fig. 2, the Al_2O_3 content is maximum in current density of 2 A/dm^2 therefore, the microhardness of the coating in this current density is maximum. It has been reported that the Orowan mechanism, grain refinement strengthening and particles strengthening, play roles in increasing the deposited coatings microhardness.

For examining the current density effect on corrosion behavior of the produced coatings, the potentiodynamic polarization method was used. The polarization curves corresponding to all of the samples in 3.5 wt% NaCl at ambient temperature are depicted in Figure 5. It can be seen that by increasing of the current density the corrosion potential shift to negative values. The corrosion behavior of the produced coatings is affected by coatings composition, surface morphology of the coatings, and the content of the Al_2O_3 particles. Figure 5 shows that by increasing the deposition current density, the roughness and porosities in the coatings increase. Therefore, the steel substrate can be exposed to the corrosion media via the porosities. In this case a galvanic coupling is created between the coating and the substrate that decreases the corrosion resistance.

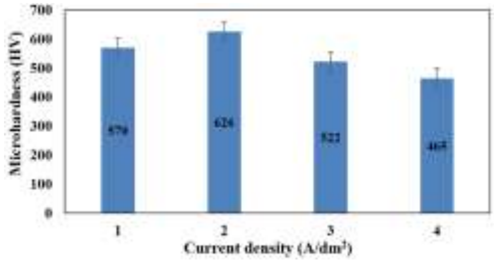

Fig. 4. The microhardness of the coatings versus current density

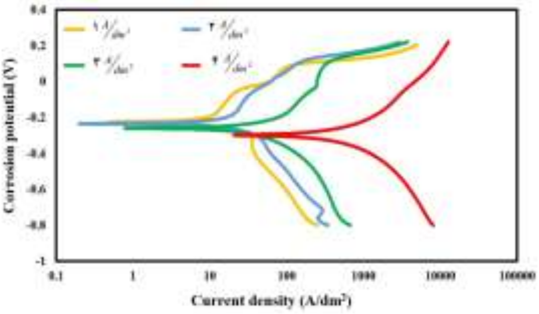

Fig. 5. Potentiodynamic polarization curves of the coatings in various current densities

The inert Al_2O_3 nanoparticles cover some parts of the coating surface and reduce the contact area between the matrix and corrosive environment. In addition, they formed many corrosion micro cells in which the Al_2O_3 particles acts as the cathode and matrix around them acts as the anode. These micro cells reduce localized corrosion and facilitates anodic polarization. The produced coating in current density of 1 A/dm^2 has a rough surface with low porosities. Also, the content of its reinforcement is high thus it has maximum corrosion resistance rather than that of other coatings.

4. Conclusion

1. By increasing the depositin current density, the Ni value increases and Cu value decreases.
2. Amongst the produced coatings, the 2 A/dm^2 nanocomposite coating indicated the maximum reinforcement value and microhardness.
3. The corrosion resistance of the produced composite coating is reduced by increasing the depositin current density.