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2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG) | 979-8-3503-5815-5/24/$31.00 ©2024 IEEE | DOI: 10.1109/SEB4SDG60871.2024.10630056

Wear Characteristics of Electro-deposited Ni-Cu-In Nanoparticle coatings for Automotive Application

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***Abstract*— Despite the massive application of Al-Mg-Si alloy in automobile and engineering components, its application in high friction and aggressive environment are limited due to low corrosion resistance, low hardness and poor resistance wear. This research is aimed at modification of the microstructure and thus enhances the microhardness and corrosion properties of Al-Mg-Si alloy. The low-carbon steel was electrodeposited with Ni-CuO and varied In3O5 (1wt%-5wt%) in the Ni-based solution. Scanning electron microscope (SEM) used to study the microstructural evolution in the fabricated coatings. As well, the microhardness of the coatings were measured using Vickers hardness tester machine. The wear properties of the fabricated coatings were studied using an Anton-paar tribometer. With respect to Al-Mg-Si alloy as the substrate, the microstructure and hardness of Ni-CuO/In3O5 coatings on the substrate were enhanced. The coatings also present good metallurgical bonding.**

Keywords*— *Ni-Cu-In Coatings; Electro-deposition; Wear Mechanism

I. INTRODUCTION

Coatings fabricated via electro-deposition have gained research interest attributed to their high hardness, good resistance to wear, and corrosion. Nonetheless, this characteristic feature depends on the coating composition, the volume fraction of constituent elements in the composition, and the co-deposited particle distribution [1]. Other factors that influence coating behavior are the deposition parameters, the applied current, the surfactant, and electrolyte concentration. The attention of electro-co-deposited coatings is mostly directed toward the optimization of the fabrication process with limited reports on the wear characteristics of electrodeposited coatings on Aluminium based composites for automotive applications [2]. The Ni-Cu coatings are reported to positively influence the characteristics of the deposit by improving the corrosion resistance [3]. Electrodeposited Ni-Cu coatings have been reported to be a better replacement for Monel as a bulk material [4]. The electro-co-deposition process is widely used for these coatings attributed to their affordability, scalability, and the possibility of controlling the coating composition and process through the optimization of the deposition parameters [5]. However, the major challenge with the electrodeposition of Ni-Cu coatings is the gap in the reduction potentials [6]. Hence, the addition of alloying elements to the electrodeposited Ni-Cu composition has a significant effect on the deposits [7]. The Ni-Cu-P deposits were reported to have refined modular structures [8, 9]. While the Ni-Cu-Mo coatings showed good corrosion resistance similar to Monel alloy [10]. However, limited reports in the literature exist on the Ni-Cu/In coatings for automotive applications. Hence, this study investigates the electro-co-deposition of Ni-Cu/In coatings on Al-Mg-Si substrate to study the microstructural and wear characteristics of the coatings for automotive applications.

II. METHODOLOGY

Nickel stripes were prepared for the anode while aluminum substrate with the chemical composition listed in Table 1, having dimensions of 40mm × 40mm × 2mm, was the cathode. Boric acid was used as a buffering agent while glycine was used as a surfactant to improve the quality of the coatings and lower the surface tension of the suspension resulting in good adhesion.

TABLE 1: CHEMICAL COMPOSITION OF A6063 ALUMINUM ALLOY (wt.%)

Composition	Si	Fe	Cu	Mg	Al
A6063	0.51	0.269	0.031	0.66	Balance

The substrate was prepared by rinsing it in deionized water after dipping it into a hydrochloric solution for less than 5 seconds. The bath was subjected to continuous stirring and prepared a day before deposition at 350 rpm to prevent particle agglomeration and enhance the solution electrophoresis while the pH of the bath was adjusted to 4.3 with the addition of potassium hydroxide and hydrochloric acid. The electro-deposition parameters followed are listed in Table 2 while the chemical composition of the electrolytic bath showing the different volume fraction of the Ni-Cu/In coating is listed in Table 3.

TABLE 2: ELECTROPLATING PARAMETERS

Time	10 Minutes
Voltage	3 V
Current Density	2 A/cm2
Temperature	25˚C

TABLE 3: CHEMICAL COMPOSITIONS OF THE ELECTROLYTIC BATHS

Composition	Bath 1 (g/L)	Bath 2 (g/L)	Bath 3 (g/L)
NiO	50	50	50
Cu2O	5	5	5
Ni Chloride	70	70	70
In2O3	1	3	5

Microstructural and phase analysis

Scanning electron microscopy (SEM) equipped with energy dispersive X-ray (EDS) was used for microstructural and chemical composition analyses. Phase of the coating alloys were identified using the PANalytical X-ray diffraction machine that used a Cu source. During data acquisition the Cu source was excited with a current and voltage of 40 mA and 54 kV, respectively.

Tribological analysis

The tribological behaviour of the developed coatings on Al-based alloys was investigated by means of Anton Paar tribological test equipment. In the test, a stainless-steel ball-on-disc was utilized in the test. 15N was used as the applied load with a sliding distance of 3mm. The dry tribological test was run for 15mins.

III. RESULTS AND DISCUSSION

3.1 Microstructural and Phase Analysis

Figure 1 presents the morphological evolution of developed coatings on Al-based alloys for potential automobile applications. The SEM/EDS was used to capture the micrographs of the synthesized coatings. The results above shows that Ni-5Cu-1In exhibit the minimum texture via observation while on the other hand, 3wt% In and 5wt% In presented high texture. Generally, the coatings exhibit good morphology with adorable structural grain and smaller particulate within the interface. Ni-5Cu-1In has fine and compact grains. It is evident from literature that fine grains are attributed to good mechanical and electrochemical properties. Ni-based coatings are characterized by rough microstructure and dominated by presence of surface defects. However the addition of InO has resulted in reduced surface defects. Homogeneousness of particles in the coating moderates the active spots for chemical and mechanical degradation by filling the pores and micro holes present on the surface of the matrix.

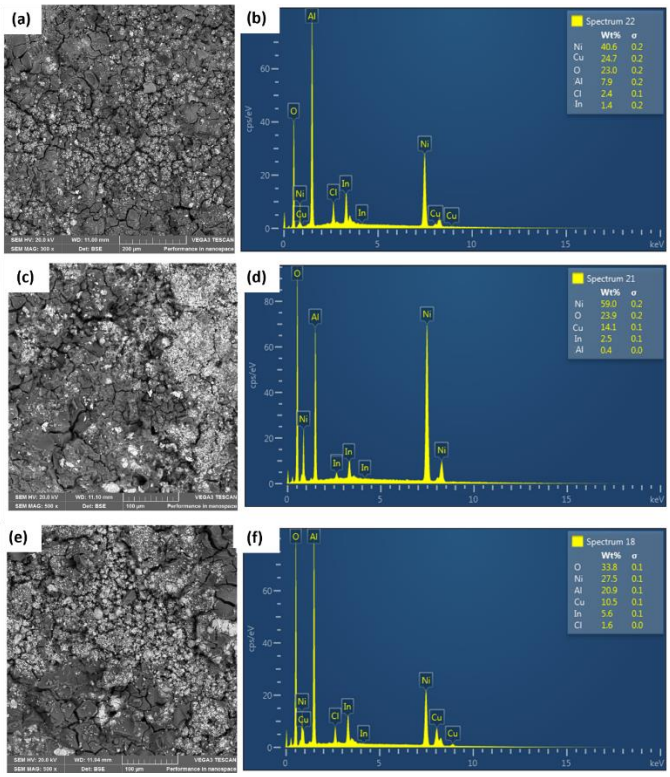

Figure 1: SEM/EDS Showing the Surface Morphologies of the Ternary Coatings of (a) Ni5Cu-1In (b) Ni5Cu-3In and (c) Ni5cu-5In

The micrographs of the phases present in the ternary coatings are shown in Figure 2. The XRD results reveal that there was uniformity in the arrangement of the crystal structures of the fabricated coatings. The major phases of Cu with the (111) cubic structure at 43.317˚ and the major peak comprising Nickel Copper oxide with empirical formular Cu0.25Ni0.75O and a (111) cubic structure at 2 θ = 37.122˚ were also evident as a secondary peak. The structural properties fabricated ternary thin films are known for good mechanical properties.

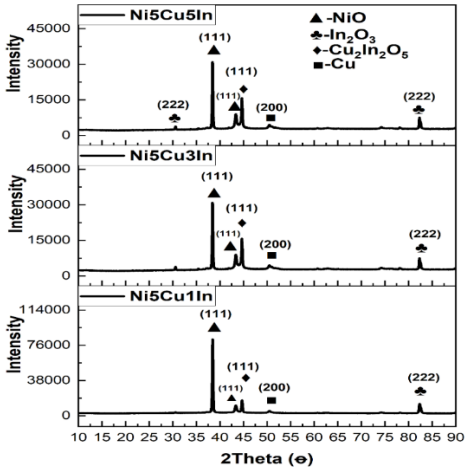

Figure 2: XRD Showing the Phases of the Ternary Coatings of (a) Ni5Cu-1In (b) Ni5Cu-3In and (c) Ni5cu-5In

3.2 Tribological Results of Ternary Coatings

Figure 3 shows the variation of coefficient of friction (COF) of electrodeposited Ni-Cu-In ternary coatings via electrodeposition technique. This demonstrates the response of the synthesized coatings to the working load of 3N under abrasive environment. The sliding duration during tribological cyclic test of the sample was 15min. From the results, there is a general trend between In2O3 composition and COF. It is clear that high wt.% of In2O3 in Ni-Cu based coatings resulted in increased COF. This means that the coatings at high wt.% of In2O3 can easily wear off due to high COF between the coatings and the contact stainless steel ball. These may be attributed to the hardness test results, which also showed that high microhardness have a relationship with the tribological properties of the alloys. The poor distribution of the phases in the alloy coatings are responsible for the COF noise experienced. Generally, Ni-5Cu-3In presented good tribological performance with low COF, showing that the coating does not wear off easily under the applied conditions

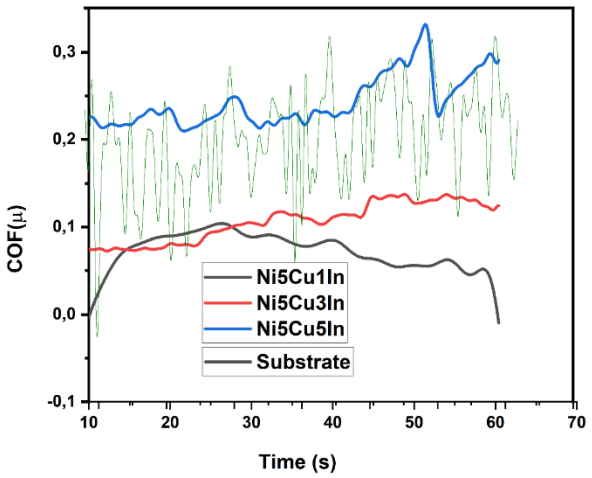

Figure 3: COF of Ni-Cu-In Tenary coatings

IV. Conclusions

Ni-Cu-In ternary alloy coatings were synthesized on Al-Mg-Si substrate by means of electrodeposition technology for advanced automobile application. The effect of wt. % of In2O3 addition on the microstructural evolution, and wear behavior were studied.

- The morphological evolution shows no significant cracks or initiation of stress and the EDS analysis confirms the presence of the elements used to develop the Ni-Cu coatings
- The XRD phases presented major phase of NiO with crystal plane of (111)
- Ni-Cu-3In coatings resulted in low COF proving that the alloy coating is suitable for tribological application in automobile industry.

V. Acknowledgments

The authors gratefully acknowledge Surface Engineering Research Centre (SERC), the Tshwane University of Technology, Department of Chemical Metallurgical and Materials Engineering, Pretoria, South Africa. The authors would also want to acknowledge Mintek (advanced materials division) at Randburg South Africa.

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