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Research paper

The Characteristic of Cobalt-Nickel-Iron Alloy Coating Coated on Aluminium, Brass and Stainless Steel

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Abstract

Electrodeposition is a well-known and economical method in the coating industry due to its low cost and fast process. This study investigates on the charateristic of electrodeposited Co-Ni-Fe alloy coating coated on three different substrates that is aluminium, brass and stainless steel. The surface morphology, microhardness, surface roughness, and corrosion resistance of Co-Ni-Fe electrodeposited on aluminium, brass and stainless steel was determined. This study compares the different properties of the Co-Ni-Fe alloy coating coated on aluminium, brass and stainless steel which can enhance the mechanical, chemical and corrosion properties of these metals. Aluminium deposited with Co-Ni-Fe alloy coating had the highest microhardness of 427.4 Hv as compared to brass and stainless steel. Meanwhile the surface roughness for all metals deposited with Co-Ni-Fe alloy coating was reduced significantly. In terms of the corrosion behavior, brass coated with Co-Ni-Fe alloy coating has the lowest corrosion rate of $4.699x10^{-3}$ mmpy while stainless steel and aluminium had a corrosion rate of $19.82x10^{-3}$ mmpy and $66.15x10^{-3}$ mmpy, respectively. From the findings it can be seen that microhardness and corrosion resistance showed an increase of about 40% after depositing the aluminium, brass and stainless steel with Co-Ni-Fe alloy coating.

Keywords: *Co-Ni-Fe, electrodeposition, nanoparticles, microhardness*

1. Introduction

Aluminium became an economic competitor in engineering applications towards the end of the 19th century [1]. Aluminium offers a wide range of properties that can be engineered precisely to the demands of specific applications through the choice of alloy, temper, and fabrication process. The poor resistance to wear and localized corrosion of aluminium can limit its more widespread usage. When the aluminium surface is exposed to the atmosphere, a thin invisible oxide skin forms immediately, which protects the metal from further oxidation.

Brass is widely used in industrial manufacturing since it is usually the first choice material for many of the components for equipment made in the general, electrical and precision engineering industries. Brass is specified because of the good combination of properties matched by no other material where a long cost-effective service life is required. Generally, brass has excellent castability and a good combination of strength and corrosion resistance. Brass is used in applications such as plumbing fixtures, gears, bearing, decorative hardware and architectural trim [2]. Brass is an alloy made from copper and zinc and also include a small percentage of other metal like iron, nickel, lead, tin, aluminium and antimony [3].

Stainless steel is desirable and can be exploited in a wide range of applications due to its high corrosion resistance. Many possibilities of shape, colour and form, whilst at the same time being tough, hygienic, adaptable and recyclable is the main reason stainless steel is favourable in many engineering applications. Furthermore, stainless steel normally show insufficient corrosion resistance in strongly aggressive media containing CL^- and S^{2-} ions at very high temperatures.

Electrodeposition is a low energy process and therefore uniquely suited in dealing with modification of materials of various types. It may be combined with self-assembled templates to prepare nanomaterial with exciting properties [4]. Nano coating can be produced with thickness ranging from micrometres to nanometres from this method. The added values of this method are cost-effective and less time consuming in synthesizing the nanomaterial. It can be used on metals, alloys, polymers, and composites [5]. By controlling the deposition parameter, it is possible to achieve a change in thermal composition, mechanical and corrosion properties of the deposited material.

Nanoparticles become a useful way in improving the material performance. Material with grain size less than 100 nm is known as nanocrystalline material [6]. These materials exhibit enhancing properties, that is, physical, chemical, and mechanical, resulting from a reduction of grain size and existence of interphase within the grain boundaries of the microstructure [7-8]. An increase in deposition temperature was most likely due to an increase in deposit grain size, which should have increased the value [9]. Most deposited coating have a dendritic and irregular microstructure because of the grains like the pine tree-like shape, known as dendrite. The formation of dendrite occurs because the grains are developed in defined planes due to the created crystal lattice. A good understanding of the relation between the corrosion properties of the nanoparticles materials and their microstructures is important.

Different time of deposition nanoparticle coating on the substrate utilizing electrodeposition system has also been considered [10].

The increase of the deposition time prompted an addition of molecule size and surface harshness. The corrosion rate also diminished with decrement size of the particle.
The surface roughness is an imperative factor that impacts the nature of the plating coating. The nature of the electroplated coating is firmly identified with the surface state and the clean level of the substrate. The thickness of the coating decreases with the increasing of surface roughness. This is because of high substrate roughness expanded the particular surface region of cathode response, diminished the present thickness and total electron amount, diminished the lessening of metal ion, and the thickness of coating decrease appropriately [11-12].

2. Methodology

The materials used in this study were stainless steel, brass and aluminium. Several machining process was needed before it could be used for the electrodeposition process. The machining process included cutting, grinding and polishing. The size of the sample followed the requiremnet of the Surftest, Vickers's hardness machine's specification. All specimens were cut with the dimensions of 25mm x 25mm.

Table 1: Bath Composition for Co-Ni-Fe Deposits

Compound	Mass (g)
Cobalt Sulphate (CoSO4)	**28.12**
Nickel Sulphate (NiSO4)	**70.08**
Iron(II) Sulphate (FeSO4)	**11.12**
Boric Acid (H3BO3)	**32.96**
Ascorbic Acid	**23.48**
Saccharin (C7H4NO3S)	**2.72**

The electrodeposition solution consist of cobalt sulphate ($CoSO_4$), iron sulphate ($FeSO_4$), boric acid (H_3BO_3), ascorbic acid, nickel sulphate ($NiSO_4$) and saccharin ($C_7H_4NO_3S$). The chemical com position is as shown in Table 1. Saccharin is used as a grain refiner while boric acid is used as a pH buffer. All of the components come in powder form. Distilled water was then added in the beakers and a magnetic stirrer was used continuously to make sure the solution dissolves homogenously. The electrodeposition process was carried out for 1 hour for all samples.
In this research, Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray (EDX) and surface roughness characterization were conducted to investigate the effect of Co-Ni-Fe alloy coating on the surface of aluminium, brass and stainless steel. EDX was used to determine the chemical compositions, crystalline structure and crystal orientations. High-energy electrons focused beam were used to generate a variety of signals at the surface of the solid specimens. The SEM is capable of performing analyses of selected point locations on the sample. Meanwhile, EDX is an analytical technique used for the elemental analysis or chemical characterization of the material. The significance of the test is to identify the characteristic of the structure in the deposited coating.
Corrosion behaviour of the electrodeposited coating was conducted by using the potentiodynamic polarization (PDP) test. The PDP test was performed at room temperature in a 1M hydrogen chloride (HCL) solution with pH 5.2. Corrosion parameters were calculated on the basis of cathodic and anodic potential versus current density characteristics in the Tafel potential region.
On the other hand, Surftest machine were used in order to identify the surface roughness of the nanocrystalline Co-Ni-Fe alloy coating. During the test, different spot on the coating surface was taken to analyze in order to obtain the average value of surface roughness profile, Rα.
Vickers Micro hardness Tester was used to identify the hardness of the nanocrystalline Co-Ni-Fe alloy coating on the samples. Constant 1kg load was used as the indention load. Five different spots were taken and the average micro hardness was calculated.

3. Result and Discussion

3.1. Scanning Electron Microscopic and Energy Dispersive X-Ray (EDX)

3.1.1. Aluminium

Scanning Electron Microscopy (SEM) characterized the microstructure of the coating deposited on aluminium as shown in Figure 1. It can be seen that the morphological structure of the coating surface was in a spherical shape. The surface of the coating on aluminium also showed appearances of micro cracks. This maybe due to the oxide layer formed at the surface of aluminium specimen which prevented the Co-Ni-Fe alloy coating to fully coat on the aluminium surface. Besides that, the micro cracks maybe also due to the entrapment of the hydrogen and existence of the Ni element at the aluminium surface [13]. Formation of voids affects the mechanical properties of the aluminium specimen. It will cause the adhesion between the top surface of aluminium with the deposited Co-Ni-Fe coating which can become weak.
Energy Dispersive X-ray test was used to determine the composition of the elements of the Co-Ni-Fe alloy coating. In order to determine the elemets that exist in the Co-Ni-Fe coating, all the data from the graph was compared with the standard library data for Co-Ni-Fe compound. All the results obtained from the Co-Ni-Fe coating showed the identical patterns in term of their trend of peak position and compound existed on the coating. A chemical analysis of the coating is obtained from the EDX spectra as shown in Table 2. On the surface coating, 1.0 wt% of oxygen was present. The oxygen was present probably due to coating at high temperature. The other elements that exist on the surface coating of aluminium were iron, nickel, zinc and cobalt which had the highest composition of 42.7 wt%.

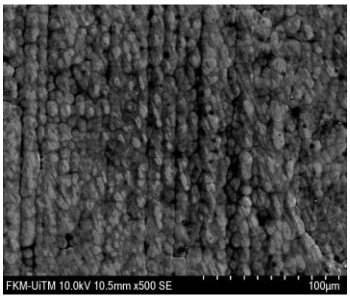

Fig. 1: SEM microstructure of CoNiFe coated aluminum

Table 2: Elemental composition of CoNiFe coatings on aluminium

Element	Carbon	Oxygen	Ferrous	Cobalt	Nickel
Weight %	7.7	0.8	15.2	42.7	34.0

3.1.2. Brass

Figure 2 shows the SEM microstructure of the brass after depositing the Co-Ni-Fe alloy coating. It can be seen that a smooth Co-Ni-Fe coating was formed on the surface of the brass. However, few black spots could also be observed on the surface coating. This maybe due to the presence of carbon element at the surface of the brass after the coating process. Meanwhile, from the EDX test it can be seen that cobalt, iron and nickel was present on the surface coating of brass as shown in Table 3. Other elements that existed on the coated brass were carbon and oxygen.

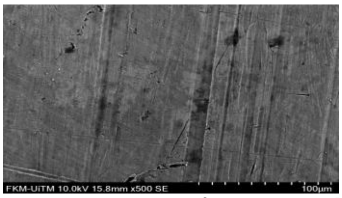

Fig. 2: SEM microstructure of CoNiFe coated brass

Table 3: Elemental composition of CoNiFe coatings on brass

Element	Carbon	Oxygen	Ferrous	Cobalt	Nickel
Weight %	22.5	1.0	13.1	31.5	31.0

3.1.3 Stainless Steel

The SEM microstructure of the deposited Co-Ni-Fe coating deposited on stainless steel is shown in Figure 3. It can be observed that an uneven surface morphology was obtained. The rough coating surface was probably due to the substrate surface that was not prepared thoroughly. The elemental composition of the electrodeposited Co-Ni-Fe coating on stainless steel was also analyzed by using the EDX analysis. Table 4 shows the elemental composition of the electrodeposited Co-Ni-Fe coating produced. The EDX confirmed the presence of cobalt (Co), nickel (Ni), iron (Fe), oxygen (O), and a small amount of carbon (C). The presence of carbon maybe due to the carbon tape that was used during sample preparation.

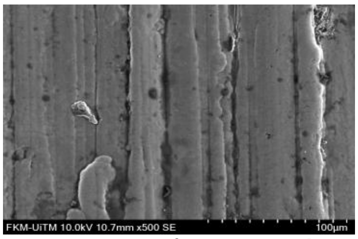

Fig. 3: SEM microstructure of CoNiFe coated stainless steel

Table 4: Elemental composition of CoNiFe coatings on stainless steel

Element	Carbon	Oxygen	Ferrous	Cobalt	Nickel
Weight %	1.1	3.1	11.7	48.4	34.0

3.2. Corrosion Behaviour

The potentiodynamic polarization testing has been done on aluminium, brass and stainless steel material. The polarization data; (corrosion potential (E_{corr}), corrosion current density (i_{corr}), and corrosion rate) are listed in Table 5. From the open circuit potential (OCP) measurement in 1 M HCL (pH 5.2), brass coated with Co-Ni-Fe coating had a corrosion potential of -409.0 mV, followed with coated aluminium and stainless steel with a corrosion potential of -403.0 mV and -364.0 mV, respectively. It had been reported that the existence of high iron content will reduce the corrosion resistance of a material [16]. The negative effect of the high Fe content in acidic solution can be observed through the current density of the corrosion potential as shown in the table below.

Table 5: Polarization data of CoNiFe coated on alumimium, brass and stainless steel

Specimen	i_{corr}	E_{corr}	Corrosion rate (mmpy)
Aluminium	35.10	-403.0	$66.15x10^{-3}$
Brass	1.570	-409.0	$4.699x10^{-3}$
Stainless steel	2.470	-364.0	$19.82x10^{-3}$

Co-Ni-Fe coated on aluminium had higher current density of 0.035 mA cm^{-2} as compared to brass and stainless steel. Based on previous studies [17], the decrease in the corrosion resistance of the Co-Ni-Fe coatings were due to the addition of saccharin in the plating bath solution. The use of saccharin caused the existence of sulphur on the surface material which is known to be a corrosive element and thus reduces the corrosion resistance of a material. Between the three type of substrate used for coating Co-Ni-Fe, brass had the lowest corrosion rate which is only $4.699x10^{-3}$ mmpy, followed by stainless steel and aluminium which is $19.82x10^{-3}$ mmpy and $66.15x10^{-3}$ mmpy, respectively. Figure 5 shows the potentiodynamic polarization curves obtained for all the three substrates used to coat Co-Ni Fe. From the figure it can be seen that the pattern of the corrosion rate between this three types of substrate material are almost similar. The presence of the relatively spherical particles has shaped the interphases known as particle boundary. The quantity of limit in the Co-Ni-Fe microstructure was increased because of the disoriented alignment and nanoparticles sequencing. In a dense structure, the diffusion of the oxygen to make the corrosion resistance lower due to coating process could be prevented. Based on the previous research, the existence of the voids at the surface material will also cause an increase in the corrosion rate [18]. Voids may occur due to the arrangement of oxide between grains.

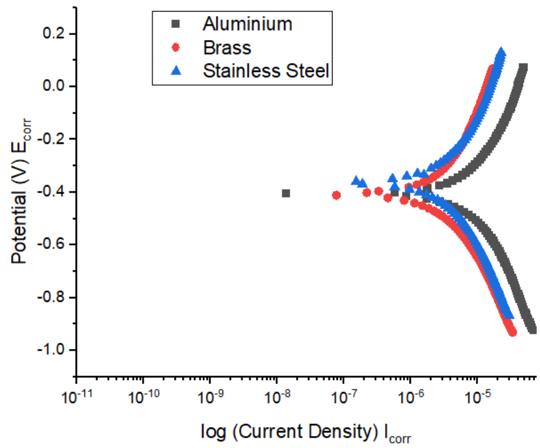

Fig. 4: Potentiodynamic polarization of CoNiFe coated on aluminium, brass and stainless steel

3.3. Surface Roughness

The surface roughness test was used to determine the value of surface roughness of the Co-Ni-Fe alloy coated on aluminium, brass and stainless steel. This test compared the surface roughness between the coated specimen and un-coated specimen. This test used the Surftest machine. Figure 5 and 6 shows the average value of the surface roughness obtained between the coated specimen and un-coated specimens for all three substrates. From the figures shown, it can be seen that different surface roughness values were obtained between the coated samples and un-coated samples. One of the factors that affected the surface roughness is the deposition time and formation of void at the surface material [18]. The increasing of the value in surface roughness was due to the formation of the voids. However, the aluminium substrate showed different results as compared to the brass and stainless steel substrate. The aluminium substrate deposited with Co-Ni-Fe coating showed the highest value of Ra as compare to the un-coated aluminium. The surface roughness of the coated aluminium has an increase from 0.24 µm to 0.46 µm. Based on the previous research [5], this is probably because of the increasing in nuclei density. The longer the process of deposited time, the larger the nuclei density. The surface roughness of the coated sample is due to the iron composition between each substrate and Co-Ni-Fe alloy coating. Meanwhile, Co-Ni-Fe coated on brass showed a decrease in surface roughness. The surface roughness of the coated brass decreased from 0.71 µm to 0.41 µm while for stainless steel, the surface roughness improved significantly from 2.13 µm to 1.703 µm.

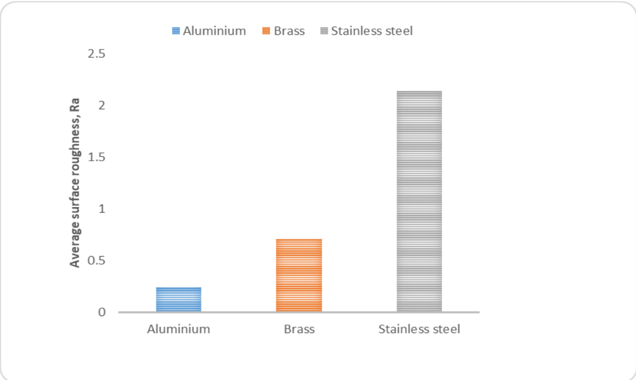

Fig. 5: Surface roughness of uncoated aluminium, brass and stainless steel

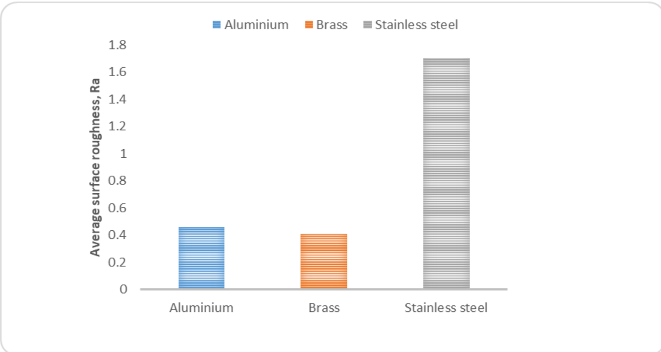

Fig. 6: Surface roughness of CoNiFe coated on aluminium, brass and stainless steel

3.4. Micro Hardness

The microhardness properties of the specimen were measured by applying Vickers's hardness test. In this test, the microhardness between coated and un-coated aluminium, brass and stainless steel was measured. All the reading was done 5 times to obtain the average value of the microhardness with a constant intender of 15 g load. The microhardness of the uncoated substrates is shown in Figure 7 while the microhardness of Co-Ni-Fe coated aluminium, brass and stainless steel is shown in Figure 8. It could be observed that all three types of substrate used had an increment in microhardness after Co-Ni-Fe was deposited. The aluminium substrate had the highest value in microhardness which was 427.04 Hv. This shows that aluminium coated with Co-Ni-Fe alloy coating have good performance in hardness. For the brass substrate, the microhardness also increased from 169.09 Hv to 343.2 Hv after deposited with the Co-Ni-Fe coating. While for stainless steel, the microhardness also increase from 251.66 Hv to 388.38 Hv.

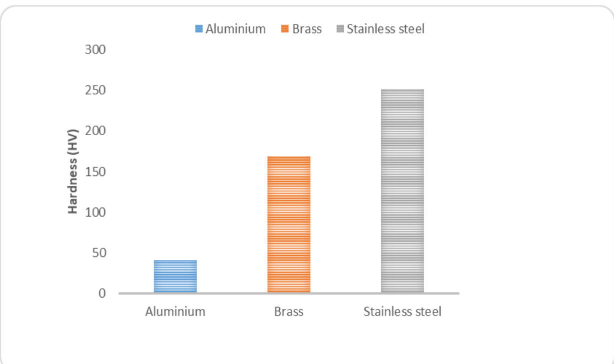

Fig. 7: Microhardness of uncoated aluminium, brass and stainless steel

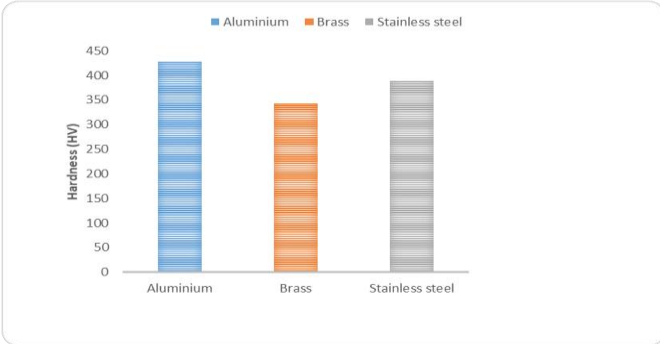

Fig. 8: Microhardness of CoNiFe coated on aluminium, brass and stainless steel

4. Conclusion

There are several conclusions that can be made from this study. From the findings obtained, deposited Co-Ni-Fe on brass has shown that a low surface roughness was obtained as compared to the coatings produced on aluminium and stainless steel substrate. From the microhardness test, Co-Ni-Fe coated on aluminium has the highest microhardness as compared to stainless steel and brass. Meanwhile, the corrosion behaviour of Co-Ni-Fe alloy coating coated on brass had the lowest corrosion rate as compared to the other two substrates. As a conclusion it can be seen that all three substrates used which was aluminium, brass and stainless steel showd an improvement in their surface properties after depositing with Co-Ni-Fe alloy coating.

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