Effect of Current Density on Hardness of Low Carbon Steel Electroplated by Copper, Nickel and Copper-Nickel

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Abstract. Coating process of metal surface undergoes rapid development, especially in electroplating method. This study aims to investigate effect of current density on hardness of low carbon steel plates electroplated by copper, nickel and copper-nickel. Low carbon steel plate coated with copper, nickel and copper-nickel using electroplating process with current variation (6, 9, 12 A for copper coating), (2.5, 3.5, 5 for nickel coating) and (2.5, 3.5, 5, 6, 9, 12 A for copper-nickel coating). Electroplating time for the three processes is 20 minutes in 5-liter solution at temperature range of 55-60°C. The electroplated steel plates are characterized with micro vickers hardness test. The results of this study indicated that the highest hardness is 290 kg/mm² for nickel coating at current density of 5 A. Contrary, the lowest hardness is 111 kg/mm² in copper coating at current density of 12 A, while the hardness for copper-nickel coating is 252 kg/mm² at current densities of 12 A and 5 A.

1. Introduction

In recent decades, metal plating has evolved from an art to an exact science. There are many reasons to coat objects. These reasons include corrosion control, resistance to wear, hardness and decorative purposes. This development is seen as responsible for the ever-increasing number and widening types of application of this branch of practical science and engineering. There are some method coatings for metals range such as electrochemical and electroplating. Technology of electroplating has been known for a long time, and it has been used for preparation of coating in models of complex form (galvanoplastics), and for thin coating on subjects for the purpose of protecting metals mostly from corrosion (galvanization) as mentioned [1]. Electroplating process uses electric current and electrochemical reaction to make metal coatings. Coatings may be formed by copper, nickel, chromium, zinc, tin, cadmium, silver, gold and others. Electroplating is one of the most difficult surface adjustment technologies for pre-treatment products. It is clear, because the transmission of metal ion from solution on the surface of cathode and its incorporation to the crystal grid require perfect contact of phases. Selection of technology depends on the type of electroplating products and bath, electroplating technique, condition of surface and technical equipment of electroplating plant [2]. Nickel is one of the most important metals applied by electro-deposition [3]. Nickel plating for low carbon steel is widely used in industry application due to its benefit in...
improving corrosion fatigue life, increasing plating thickness to provide good protection against corrosion. Copper electroplating is widely used in the electronic industry for fabrication of electronic devices. It is particularly explored for fabrication of printed circuit boards and semiconductors. High throwing power copper electrolytes are becoming increasingly important due to electronic industry requirements for manufacturing of high aspect ratio circuit boards. Effect of plating parameters such as current density, electrolyte pH, electrolyte concentration, plating medium temperature, plating time, material size and plating bath volume on the mechanical properties must be investigated to obtain optimum parameters. Current density management is important for two main reasons. Firstly, the current density controls the rate of deposition. Secondly, the current density must be controlled within the correct operating range in order to obtain sound deposits having uniform appearance and free from burning or treeing. The purpose of this project is to study the effect of current density of on hardness of low carbon steel electroplated by copper, nickel and copper-nickel. This will enhance the engineer to have a formal knowledge on when and how to apply a particular concentration for a particular purpose such as in corrosion control, decorative purpose, hardness and wear resistance.

2. Process of Electroplating

The electroplating process essentially involves passing an electric current between two electrodes immersed in an electrolyte. The positively charged electrode is anode while the negatively charged electrode is the cathode. The electrolyte contains electrically charged particles or ions. When an electrical potential or voltage is applied between the electrodes these ions migrate towards the electrode with the opposite charge-positively charged ions to the cathode and negatively charged ions to the anode. This results in the transfer of electrons, that is a current flow, between the electrodes-thus completing the electrical circuit [5]. Copper is soft, tenacious and not too oxidized to air. Because of its nature, being electropositive, copper is likely being gravitated to less-conductive metals, like iron. Copper plating is easily conducted, and so is its liquid controllable. Copper is appropriate to be utilized as the base coating prior to the following plating [4]. Nickel plating is used to prevent corrosion or to heighten luxury. Nickel is resistant to heat, not corrosive and preventable to salty water, freshwater and alkali. Nickel can be decayed by nitric acid and somewhat corrosive by cline acid and sulfuric acid. Nickel also has rigidity and medium endurance, ideal tenacity, fine conduction and good thermal. Generally, in electroplating, the anodes are composed of the metal being plated. These are referred to as ‘soluble’ anodes. During electroplating, the positively charged metal ions discharge at the cathode (the component to be plated) depositing metal on the surface. The component being plated therefore receives a coating of metal. The reverse effect occurs at the anode and, with a
soluble anode, metal ions are formed through dissolution. The electrical energy is supplied by a DC power source such as a rectifier. The basic electrical circuit is depicted in figure 1.

![Figure 1. Basic electrical circuit](image)

3. Experimental Procedure

The substrates were low carbon steel plate with a hardness of 107 HVN. The plate dimensions were 55mm×20mm×4mm as shown in figure 2. Chemical composition of the substrate is shown in table 1. Before deposition, the substrates were mechanically polished surface roughness using sandpapers. Three electroplated coating processes were performed namely Cu, Ni, Cr-Ni coating. Cu coatings were electrodeposited with a bath containing copper cyanide (45 g/L), sodium cyanide (64 g/L), rochelle salt 30 (g/L) and caustic soda (20 g/L). The deposition current density were varied in three conditions (6, 9 and 12A) in the temperature range of 55-60 °C in 20 s at pH of 3.6. Ni coating were electrodeposited by using a bath containing nickel sulfate (250 g/L), nickel chloride (50 g/L), boric acid (45 g/L) and brightener 1( g/L). The deposition current density were varied in three conditions (2.5, 3.5, and 5A) in the range temperature 55-60 °C in 20 s at pH of 4.7. Cr-Ni coatings were firstly electroplated with Cu coating bath in 10 s. Then it were continued with Ni coating bath in 10 s. Three kinds of substrates were treated by combining of Cu-Ni coating, i.e (6A Cu - 2.5A Ni, (9A Cu – 3.5A) and (12A Cu – 5A Ni).

| Elements | Composition (%) |
|----------|-----------------|
| C        | 0.18            |
| Si       | 0.08            |
| P        | 0.10            |
| Mn       | 0.62            |
| Ni       | 0.75            |
| Mo       | 0.082           |
| V        | 0.005           |
| Ti       | 0.002           |
| Al       | 0.006           |
| Mg       | 0.004           |
| Sn       | 0.0008          |
| Fe       | 97.60           |
4. Results and Discussion

Effect of Current Density

The hardness and layer thickness of the substrate in copper plating technique with different current density were shown in figure 2. The hardness of the substrate at current density of 6, 9 and 12A were 118, 107 and 111 HVN, respectively, while the thickness of the substrate at current density of 6, 9 and 12A were 0.023, 0.037 and 0.057, respectively. The hardest sample was obtained in the thickness of 0.023mm with current density of 6A. The results indicated that the hardness of substrate increases with increasing of current density. In contrast, the thickness of substrate increases with increasing of
current density. The hardness and layer thickness of the substrate in nickel plating technique with different current density were shown in figure 3. The hardness of the substrate at current density of 2.5, 3.5 and 5A were 118, 190 and 290 HVN, respectively, while the thickness of the substrate at current density of 6, 9 and 12A were 0.023, 0.037 and 0.057, respectively. The hardest sample was obtained in the thickness of 0.093mm with current density of 5A. The results indicated that the hardness of substrate increases with increasing of current density. Moreover, the thickness of substrate also increases with of current density increasing. The hardness and layer thickness of the substrate in copper-nickel plating technique with different current density were shown in figure 4. The hardness of the substrate at three combination of current density of (6A Cu - 2.5A Ni, (9A Cu – 3.5A) and (12A Cu – 5A Ni) were 144, 194, and 252 respectively. Moreover, the thickness of the substrate for three combinations of current density i.e. (6A Cu - 2.5A Ni, (9A Cu – 3.5A) and (12A Cu – 5A Ni) were 144, 194, and 252 respectively. The hardest substrate was obtained in the thickness of 0.080mm with current density combination of 12A Cu -5A Ni.

5. Conclusions

The foremost task of this study was to investigate the effect of current density of copper, nickel and copper-nickel electroplating of low carbon steel alloy. According to the obtained results, the subsequent conclusions can be summarized: the hardness of electroplating of low carbon substrate was affected by current density and types of electroplating process. The highest hardness in copper, nickel dan copper-nickel electroplating was 118 kg/mm2 (6A), 290 kg/mm2 (5A), and 252 kg/mm2 (12/5A), respectively. The substrate hardness in nickel electroplating is higher than that in copper electroplating.

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