The Influence of Variation of Electrical Current and Electroplating Process Time on Coating Thickness, Glossiness and Adhesion of Copper on Low Carbon Steel

Deny Hendra Cipta and Ismail Ramli
Heavy Equipment Engineering Study Program, Nunukan State Polytechnic, Nunukan, Indonesia

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Abstract: The electroplating process is widely used for various purposes, such as; decorative applications, improving the base material properties such as wear resistance, electrical conductivity, corrosion resistance, and the dimensions and geometry of a work piece. In this study, testing of the copper electroplating process on low carbon steel with variations in current strength and processing time was carried out. Electric currents used are 5 Ampere, 10 Ampere, and 15 Ampere. The processing time is 20 seconds, 40 seconds, and 60 seconds. An acidic copper solution was used as the electrolyte, with a nickel layer as the base coating layer. The plating results were then tested for thickness, glossiness, and adhesion. Test results show the effects of electrical current and time on coating quality. 5 Ampere current does not give a significant difference for the value of thickness, glossiness, or adhesion. While the 15 Ampere current shows symptoms of a too-large current density, such as dark color and low adhesion. The study shows that paired variations of 10 Ampere current strength with 40 seconds process time gives the best results, with a thickness of 0.78 microns, a gloss value of 46 percent, and a coating adhesion of 71.6 percent.

1 INTRODUCTION

The electroplating process is one of the finishing processes that is often needed in the metalwork process. Both in the metal industry and machinery production. The final finishing process varies, some are simply polished to make it smooth and shiny, can also be coated with other metals with the aim of improving the properties of the base metal, some are painted or varnished or coated with ceramics. Finishing is also preferred for metals that are easily corroded. One common method to achieve this purpose is throuh electroplating process (Kumar et al., 2015; Purwanto and Huda, 2005).

Copper (Cu) is one of commonly substance used for electroplating processing. This material is a good electric and heat conductor. Copper is used as a base coat because it can cover the surface of the material being coated and has good leveling ability. A copper base plating is required for further plating with nickel which can then, be followed by a chrome, brass, silver or gold plating. Its characteristic gives the demanded final products properties. Copper plating used on plastics, rotogravure rolls, printed circuit board, semiconductor manufacturing and also widely used as coating on steel wire to increase conductivity (12%). Copper can be utilized as leveling material in electrorefining and electroforming. It has a decorative value if applied on the surface and buffed. Coat of copper also can act as an heat inhibitor in metal selective heat treatment (Purwanto and Huda, 2005; Dini and Snyder, 2020; Lowenheim, 1978).

To achieve the purposed uses, the electroplating results need to have a certain level of quantity and quality. To be used as an effective conductor material the plated layer has to be at a certain thickness. The surface glossiness of the end result is highly demanded for decorative purposes and also the layer adhesion strength to its substrate is important when used as inhibitor in selected parts of heat treated components. To get a good coating quality, there are several influencing factors, such as surface condition of coated base material, coating anode quality, electrolyte quality, process temperature, electrical current and process time. These parameters must be studied to achieve

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optimum results (Fotovvati et al., 2019; Aygar, 2009).

The modelling and optimization pf copper electroplating adhesion strength was conducted by Suryanto et al. (2017). The base material investigated was stainless steel which coated with copper through elctroplating with variation in the copper content in the electrolyte and also variation of the current density. The adhesion strength was tested using Teer ST-30 tester. This study finds the highest current density gives the highest adhesion strength.

Margen et al. (2018) studied the effect of process time of 60 seconds, 120 seconds, and 180 seconds on electroplating nickel layer upon AISI 304 stainless steel and copper with an enhancement from an ultrasonic batch. The findings of this work tell that the longest process time gave the highest thickness number and the conclusion is that the electroplating process time has a direct relationship to level of thickness formed on the research test subject.

The effect of current density on hardness and thickness properties of copper coating on low carbon steel has been studied (Sudarsono et al., 2020) This study varies the current density of 6, 9, and 12 Ampere. The result shows the highest current density variables gave the thickestcoating layer and also resulting the hardest copper layer on the test specimen.

This study aims to understand the effect of some variables against different aspects and needs from copper coating quality at the same time. The layer thickness relates to mechanical properties such as wear-resistance and hardness. The glossiness value is directly related to the function of copper coating as a decorative value enhancer. The adhesion test is needed to understand the effect of heat and sudden temperature changes to the durability of coated copper layer for instance in the use of copper coating as a barrier in selective heat treatment. Process time and electrical current are two of the main basic controllable variables in electroplating process, thus having a deep understanding about this parameters would have a great impact on producing quality coating layer.

2 RESEARCH METHODOLOGY

2.1 Research Method Flowchart

The research flowchart is as shown in Figure 1.

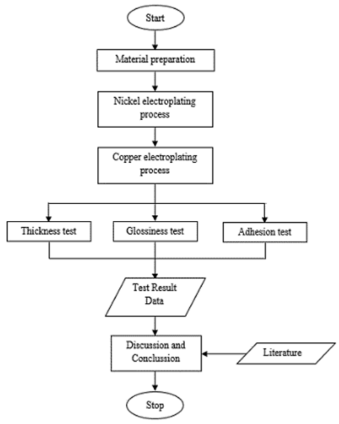


Figure 1: Research method flowchart.

2.2 Preparations

In this stage, activities planning is arranged and the materials are prepared for the testing and research activities stage.

2.2.1 Test Design

In this test, there are two variables, the current strength and processing time. Where for the current strength variation used is 5 Ampere, 10 Ampere and 15 Ampere. As for the variation of processing time, the selected time is 20 seconds, 40 seconds and 60 seconds.The material to be coated is low carbon steel with nickel ,and copper as plating materials.

2.2.2 Equipment

In this study, several equipment and tools were used for the implementation of activities.

a) Electroplating Process Equipment

The equipment used in this electroplating process are plate cutting tool, polishing machine, coating tub, compressor, Ampere meter, rectifier

b) Testing Methods and Equipment

- Layer Thickness Test

The layer thickness test aims to determine the thickness of the copper deposit layer on the surface of the workpiece after the electroplating process. The thickness test here uses the Inverted Metallurgical Microscope.

- Glossiness Test

This test aims to determine the level of surface glossiness of the test speciments, which is related to the decorative value of the results of the electroplating process. The glossiness test is carried out using a Lux meter.

- Adhesion Test

This test aims to perceive the adhesiveness property of the copper electroplated layer on the surface of substrate material. The test, named heat quench test [lowenheim] where the testing factor is the high temperature obtained by heating objects in an electric furnace and then the speciment subsequently quenched in water at room temperature. The heat and sudden temperature changes will affect the strength of adhesion of the electroplated copper layer to the base material. The layer's adhesion strength is measured by differentiating the percentage of the test specimens surface area left covered with the copper layer after the heat quench process. The surface area is calculated using a transparent millimeter block [3].

2.2.3 Materials

The coating material (anode) is copper while the material to be coated (cathode) is a low carbon steel plate with a size: 50 mm long, 25 mm wide and 2 mm thick. The dimensions of the test object are shown in Figure 2.

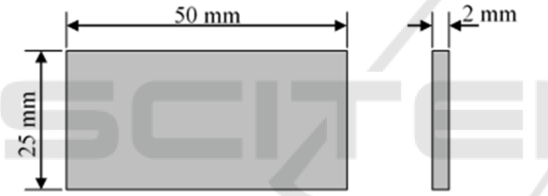


Figure 2: Test object dimension.

2.2.4 Electrolyte

a) Composition of Nickel Solution

The composition of the solution in 1 litre of distilled water:

- Nickel sulfate, $NiSO_4.6H_2O$ = 240 - 300 gram/litre
- Nickel chloride, $NiCl_2.6H_2O$ = 40 - 60 gram/litre
- Boric acid, H_3BO_3 = 25 - 40 gram/litre
- Brigthener Magnum SS =2.5 cm3/litre
- Brigthener Magnum AM = 2.5 cm3/litre
- pH 1.5− 4.5

b) Copper Solution Material

The composition of the solution in 1 litre of distilled water:

- Acid copper, $CuSO_4$ = 195 - 250 gram/litre
- Sulfuric acid, H_2SO_4 = 45 - 90 gram/litre
- Hydrochloric acid, HCl = 40 – 80 mL/litre

2.3 Method of Data Collection

The data collection for this research was carried out by conducting experiments on the copper plating process with different parameters of electrical current strength and processing time, with the purpose of understanding the effect of changing these parameters on the thickness, gloss and adhesion of the copper layer resulting from the electroplating process. The results of the data tests are then compiled and documented. Then an analysis of the interconnections between the test results and the process parameters is performed, to obtain conclusions about the research conducted.

2.4 Electroplating Process

The electroplating process is carried out in several stages, namely the preparation of electroplating equipment, the preparation of electrolyte for the nickel and copper coating, the preparation of the test object, the nickel and copper electroplating process and the final finishing process. The coating process is carried out in 2 steps. The first step is nickel plating, to form a base layer on the surface of the test object because acidic copper cannot applied directly over ow carbon. In the second step, the coating process with an acidic copper solution. Nickel plating is carried out with the same process parameters for all test objects, process time for 10 minutes and 10 Ampere current strength. The copper plating is performed with variation of current strength are 5, 10 and 15 Ampere. Variation in processing time are 20, 40 and 60 seconds.

2.5 Testing

2.5.1 Layer Thickness Test

This thickness test is carried out to determine the thickness of coating layer after the nickel and chrome plating process. This test uses a Metallurgical Microscope.

2.5.2 Glossiness Test

The glossiness test was performed using a Lux meter. This equipment works by measuring the strength of light reflection from a source (electric lamp) by the surface of the test object. As a benchmark of comparison a mirror was used, assuming that it reflects the light received by 100 (one hundred) percent. The power of light is measured in Lumens.

2.5.3 Adhesion Testing

This adhesion test uses a qualitative test with the heat-quench test method. Where the test object reaches a certain temperature and then cooled with water immersion at room temperature. The heating temperature based on the type of base material and coating material [3]. In this study the test object is heated in an electric furnace to a temperature of 250°C.

3 TEST RESULTS AND DISCUSSION

The data presented in this section are the results obtained from the research. Consists of the results of calculations for the electroplating process, data from the results of thickness test, glossiness test and coating adhesion test.

3.1 Electroplating Result Data

This research was carried out with variations in the large current and time of the coating process. In addition, the weight of the test object is also carried out before and before the coating process, which determines the weight of the object at the time it occurs. The results of the weighing are shown in Table 1.

Table 1: Actual deposition weight.

Current (Ampere)	Time (second)	Initial weight, W_0 (gram)	Final weight, W_1 (gram)	Actual deposition weight, $W_a = W_1 - W_0$ (gram)
5	20	23	23.02	0.02
	40	23	23.02	0.02
	60	23	23.05	0.05
10	20	23	23.04	0.04
	40	23	23.04	0.04
	60	23	23.06	0.06
15	20	23	23.04	0.04
	40	23	23.06	0.06
	60	23	23.05	0.05

3.2 Calculation of Electroplating Results

In this section, theoretical calculations are carried out for the copper electroplating process according to the parameters of the research carried out.

3.2.1 Calculation of Theoretical Deposit Weight

From Faraday's Law, the weight calculation at the beginning of the coating process variable is carried out. The results obtained are as in Table 2.

3.2.2 Current Efficiency Calculation

By obtaining data on weight at the time of storage and theoretical storage, it is possible to calculate the current efficiency of each electroplating process carried out. Then the current efficiency data obtained for the electroplating process in this study, which is shown in Table 3.

Table 2: Theoretical weight.

Current (Ampere)	Time (second)	Theoretical weight, W_t (gram)
5	20	0,03
	40	0,07
	60	0,09
10	20	0,07
	40	0,13
	60	0,19
15	20	0,09
	40	0,19
	60	0,29

Table 3: Current efficiency.

Current (Ampere)	Time (second)	Eficiency (%)
5	20	66, 67
	40	28,57
	60	71, 43
10	20	57, 14
	40	30, 77
	60	31, 16
15	20	44, 44
	40	31, 15
	60	17, 24

3.2.3 Current Density Calculation

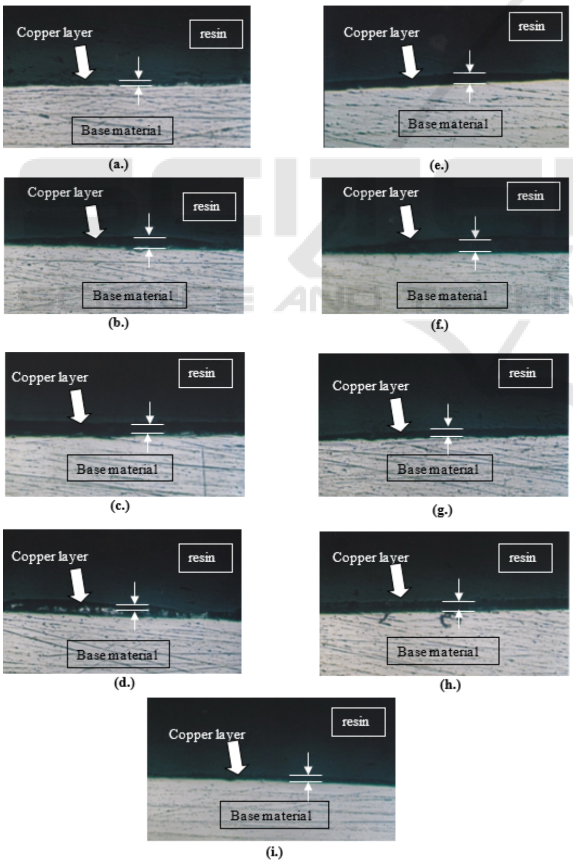
By using Faraday's Law, it is possible to find the large density that occurs in each coating process variable. Where the amount of current used is divided by the surface area of the workpiece. So that separate results are obtained which are shown in Table 4.

Table 4: Electroplating process current density.

Current (Ampere)	Surface area (dm^2)	Current density (A/dm^2)
5	0,28	17,81
10	0,28	35,71
15	0,28	53,57

3.3 Thickness Test Results

Observation of the layer is done visually with the aid of a microscope. Measurements are made by comparing the thickness with the scale lines already on the ocular lens. Measurements are made at 3 points on each test variables combination, then the calculated average is taken as the thickness value of the coresponding test object. The images from the observations on the microscope is then photographed, which is shown in Figure 3.



a.) 5 A and 20 seconds, (b.) 5 A and 40 seconds, (c.) 5 A and 60 seconds, (d.) 10 A and 20 seconds, (e.) 10 A and 40 seconds, (f.) 10 A and 60, (g.) 15 A and 20 seconds, (h.) 15 A and 40 seconds, (i.) 15 A and 60 seconds

Figure 3: Thickness test result images.

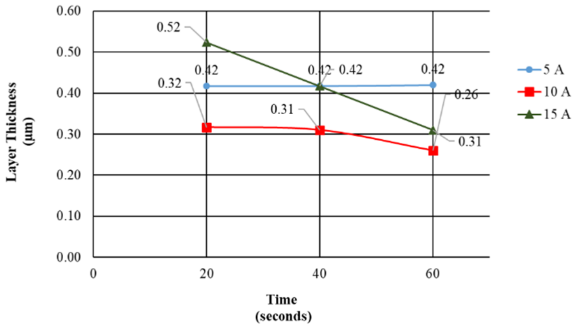


Figure 4: Process time vs layer thickness graph.

The thickness value of each test object as shown in Table 5. From the results of the tests carried out, it can be seen from the strong influence of the current coating process. Figure 4 showing the relationship between current and process, where it can be seen that the highest thickness is achieved in the 10 Ampere process with a time of 60 seconds, although at the same current, 10 Ampere with a time of 20 seconds and 40 seconds the layer formed is thinner. While in the process with a current of 5 Ampere there is no significant difference in layer thickness. This is because the current density that occurs is not sufficient to move the copper electrons to move and increase the pairing effectively.

Table 5: Layer thickness.

Current (Ampere)	Time (second)	Thickness (µm)			Average thickness (µm)
		point 1	*point 2*	*point 3*	
5	20	0.63	0.31	0.31	0.42
	40	0.31	0.47	0.47	0.42
	60	0.63	0.16	0.47	0.42
10	20	0.16	0.63	0.16	0.32
	40	0.31	0.31	0.31	0.31
	60	0.31	0.31	0.16	0.26
15	20	0.31	0.63	0.63	0.52
	40	0.31	0.63	0.31	0.42
	60	0.31	0.31	0.31	0.31

3.4 Glossiness Test Results

The degree of glossiness relates to the decorative function of a coating. The higher the gloss of the coating, the better the quality of the coating will be. This test aims to determine the effect of the current and time of the coating process on the resulting copper layer. So it is expected to know the best parameters for maximum coating quality. Lux meter scale with mirror (for comparison) is 56 lumens, which the higher the lumens number means the surface is more bright. The comparison graph of the glossiness test data for each coating process variable is shown in Figure 5.

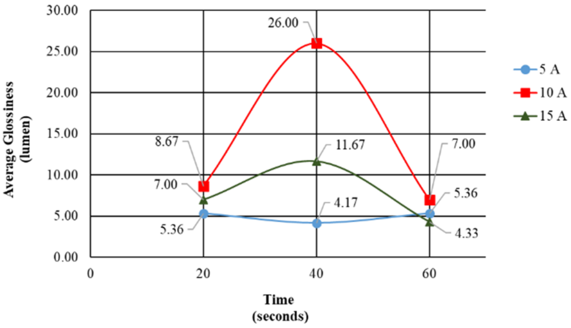


Figure 5: Process time vs glossiness graph.

From Figure 5 it can be seen that the maximum gloss level is obtained in the coating process with a current of 5 Ampere and a time of 40 seconds. This is sufficient because the copper layer formed is still thin, so the level of gloss is affected by the nickel layer used as the base layer. Where visually the nickel layer has a higher gloss than the copper layer. In the coating process with a strong current of 15 Ampere, the current density is too high which causes heat that burns the workpiece so that the layer ages or gets darker. This causes the level of gloss to decrease. In addition, gloss is also influenced by several factors, such as: the level of cleanliness and accuracy of the initial processing, stirring of the electrolyte during the process, the content of contaminants in the electrolyte, the purity of the anode and the influence of additives.

3.5 Adhesion Test Results

The adhesion strength data was obtained from the calculation of the surface area of the copper layer that was still left after the heat-quench test process. Where the surface area of the object being observed is one of the widest sides. The dimensions of the test object are; length = 42 mm, width = 25 mm which give the surface area = 1.050 square mm.

From the tests carried out, the area of the copper layer that is still left on the surface of the workpiece and the percentage of copper layer left is shown in Table 6.

The graph of the comparison of the data from the adhesion test results to the coating process time is shown in Figure 6. From the test results, it is known that the best adhesion is obtained under coating conditions with a strong current of 10 Ampere for 40 seconds. One of the reasons for this is because the current density at these conditions is good, resulting in good adhesion. In the current condition of 5 Ampere and 15 Ampere there is a drastic difference in adhesive power, both of which are related to the process current density. It's just that at the condition of 5 Ampere the current density meets the needs of an ideal coating process, while at the condition of 15 Ampere the excessive current density results in saturation of the layer, so that even though it has a good thickness, the adhesion is low. In addition, related to the level of glossiness, the pre-treatment process also affects the adhesion of the coating.

Table 6: Remaining coating layer area.

Current (Ampere)	Time (second)	Remaining layer area (mm^2)	Adhesion percentage (%)
5	20	41	3,9
	40	97	9,2
	60	36	3,4
10	20	120	11,4
	40	750	71,6
	60	49	46,7
15	20	525	50
	40	90	8,6
	60	40	3,9

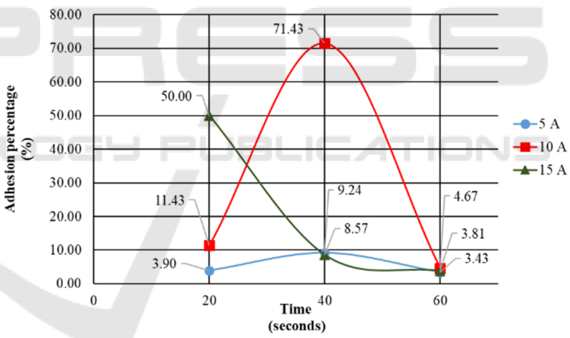


Figure 6: Process time vs adhesion percentage graph.

3.6 Discussion of the Relationship between Test Results

For the coating process with a current density of 5 Ampere, the layer formed is thin, the adhesion is low as well as the gloss value. The test results obtained for each process time also do not show significant differences. From this it is known that the electroplating process of copper with a current of 5 Ampere is less effective. Due to the low current, the covering power of the coating anode is not good which results in a thin layer and poor adhesion. Layers that have not been formed properly also affect the glossiness, so that in this test the gloss value is lower than the process with other conditions.

In the coating with a current of 10 Ampere, at the processing time of 20 seconds and 40 seconds, the layer formed is thinner, although then a layer of processing time of 60 seconds occurs. If with the value of gloss and adhesion, the coating process carried out under these conditions gives the maximum value, compared to the coating results under other conditions. It can be concluded that at a current of 10 Ampere it takes longer time to increase the thickness, the time required for the coating metal to cover the surface of the workpiece and then develop to form a layer of coating. With current density in this condition, will give coating results with good glossiness and adhesion strength.

In the coating process with a current of 15 Ampere, it can be seen the longer the time the thinner the layer, as well as the bonding of the layer. This is due to the large current density which forces the electrons to move faster than needed, resulting in a layer on the workpiece, while the growth of the layer is not perfect which affects the adhesion of the coating. For a time of 20 seconds, it gets bigger because the large current affects the formation of the layer. But as previously explained, the longer the processing time, the less effective it will be and the less the coating layer. Large currents also cause excess heat which causes a decrease in aged colors and the level of glossiness of the coating. It is very important to consider the surface area of the workpiece with the large current being used.

From the discussion carried out, to obtain copper electroplating results with maximum quality under existing constraints, 10 Ampere is used with a plating time of 40 to 60 seconds.

4 CONCLUSIONS AND SUGGESTIONS

In this the work the study of effect from electrical current and process time variations in copper electroplating were carried out. The wide application of copper electroplating with different quality characteristic needs, demand a deep understanding about the process variables. In the limitation of this study, it can be concluded that the greater current gave the largest layer deposited. For the level of glossiness and adhesiveness of the coating, the best results were obtained under coating conditions with a current of 10 Ampere for 40 seconds. This shows that large currents and longer times does not always provide the best coating quality. Current strength is related to the surface area of the workpiece which gives the value of the process current density. Where in this study, the surface area of the test object is relatively small so that large currents actually give a poor final result. Therefore, it is necessary to pay attention to the surface area of the workpiece to determine the current strength used. To better understand the electroplating process, especially with copper coatings, other studies can be carried out. Research on other process variables is encouraged, such as about current density which relates to the dimension of the object to plated, uses of additives in the electrolyte, agitation and different electrolyte bath.

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