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Effect of Current, Voltage, Temperature, and Time Variations on Thickness of Steel using Electroplating Process

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Abstrak

Penggunaan *low carbon steel* dikategorikan sebagai salah satu material pendukung dalam perkembangan industri dan teknologi karena memiliki keuletan dan ketangguhan yang tinggi. Namun, *low carbon steel* memiliki keterbatasan dalam hal ketahanan korosi. Ada beberapa cara untuk meningkatkan ketahanan korosi pada baja. Salah satunya dengan memberikan lapisan perlindungan pada permukaan baja. Metode pelapisan baja yang digunakan adalah metode elektrolisis atau metode elektroplating. Penelitian ini bertujuan untuk mengetahui pengaruh variasi arus, tegangan, suhu, dan waktu terhadap ketebalan lapisan yang terbentuk pada baja. Proses pelapisan baja dilakukan dengan proses elektroplating dimana bahan pelapis atau anoda adalah Nikel (Ni) dengan dimensi (60 mm x 30 mm x 0,1 mm). Sebagai perbandingan, benda atau katoda yang dilapisi adalah baja SK5 dengan dimensi (50 mm x 20 mm x 0,3 mm). Tujuan dari penelitian ini adalah untuk mengetahui pengaruh variasi arus, tegangan, suhu, dan waktu terhadap ketebalan baja dengan menggunakan proses elektroplating. Selain itu, semua faktor akan dioptimalkan untuk mencapai ketebalan terbaik untuk baja. Maka dari itu, ketahanan korosi SK5 dapat ditingkatkan secara signifikan dengan meningkatkan ketebalannya. Variasi saat ini digunakan 1A, 2A, 3A, dan 4A; variasi tegangan digunakan 3V, 6V, 9V, dan 12V; variasi suhu yang digunakan 30°C, 40°C, dan 50°C; dan variasi waktu digunakan 0 m, 5 m, 10 m, dan 20 m. Berdasarkan hasil penelitian yang telah dilakukan pada semua sampel, disimpulkan bahwa arus, tegangan, suhu dan waktu mempengaruhi ketebalan sampel dalam proses elektroplating. Nilai arus, tegangan, suhu dan waktu secara linier terkait dengan ketebalan yang dihasilkan dari proses elektroplating.

Keywords: *Arus, Elektrplating, Tegangan, Temperatur, Waktu*

Abstract

The use of low carbon steel is categorized as one of the supporting materials in industrial and technological developments because it has high ductility and toughness. However, low carbon steel has limitations in terms of corrosion resistance. There are several ways to increase corrosion resistance in steel. One of them is by providing a layer of protection on the steel surface. The steel plating method used is the electrolysis method or electroplating method. This study aims to determine the influence of variations in current, voltage, temperature, and time on the thickness of the coating formed on steel. The steel plating process is carried out by electroplating process where the coating material or anode is Nickel (Ni) with dimensions (60 mm x 30 mm x 0,1 mm). In comparison, the coated object or cathode is SK5 steel with dimensions (50 mm x 20 mm x 0,3 mm). The aim of this study is to investigate the effect of Current, Voltage, Temperature, and Time Variations on the thickness of steel using electroplating processes. Moreover, all factors will be optimised to achieve the best thickness for steel. Therefore, the corrosion resistance of SK5 can be significantly improved by increasing its thickness. The current variations were used 1A, 2A, 3A, and 4A; voltage variations were used 3V, 6V, 9V, and 12V; temperature variations were used 30°C, 40°C, and 50°C; and times variations were used 0 m, 5 m, 10 m, and 20 m. Based on the results of research that has been carried out on all samples, it is concluded that current, voltage, temperature and time affect the thickness of the sample in the electroplating process. The current, voltage, temperature and time values are linearly related to the thickness resulting from the electroplating process.

Keywords: *Current, Electroplating, Temperature, Time, Voltage*

1. Introduction

Steel has excellent mechanical properties which can be exploited in a wide variety of applications. It is used in construction, bridges and trusses, automotive industry, trains, and ships [1-3]. Steels are solid, durable, sustainable, and formable. However, steels are susceptible to corrosion. Corrosion is a natural condition which is caused by electrochemical reactions between the metal and its environment, which is a dangerous and expensive problem [3-7]. Globally, the estimated cost of steel corrosion is approximately USD 2.5 trillion, which is 3.4% of the global GDP (2013) [8]. Steel corrosion does harm many aspects of life. It reduces the metal thickness, leading to loss of mechanical strength and structural failure of buildings, bridges, equipment, and other structures. In addition, corrosion can lead to environmental contamination, for example, leaking pipes and fuel tanks, which can affect the health of crops and drinking water and, therefore, wildlife and humans [9,10].

A common strategy to solve this issue is surface modification using thin protective metallic coating. There are two kinds of metallic coating, i.e., sacrificial (anodic) and noble (cathodic). Sacrificial coatings provide corrosion protection by applying a thin metal layer with more negative electrode potential than the metal substrate. The coatings corrode sacrificially to ensure that the underlying substrate remains corrosion free. The best example of this type of coating is zinc. Noble coatings protect the metal substrate by applying a thin layer of metal having more positive than the electrode potential of substrate. The coatings are more corrosion resistant than the underlying metal substrate. The most common noble coating is nickel [4,11].

There are various surface modifications, and electroplating is widely used among them because it is cost-effective. Electroplating, also known as electrodeposition, is a process that uses electric current to produce metallic layer on an electrode. The electroplating process has several factors that influence the mechanical characteristics of the materials, such as potential difference, current density, layer thickness, temperature, concentration, and coating time [12]. Nickel electroplating is extensively used due to its ability to increase the lifetime of industrial, transport, and service tools and also as decorative and functionally suitable metal coating. The selection of the electroplating bath chemistry gives the required characterizations of the nickel electroplate [13, 14]. Nickel electroplating has been studied using various types of baths, such as sulphate, chloride, sulphamate, pyrophosphate, and acetate [13-20]. Acetate electrolytes are particularly appealing due to their inherent low toxicity, affordability and lack of environment impact. Nickel acetate has high degree of solubility and remarkable stability within the conventional ranges of Ph and temperature used for nickel plating. Therefore, pada penelitian yang dilakukan, terdapat perbedaan dari penelitian electroplating sebelumnya yaitu optimalisasi pengggunaan variasi arus, tegangan, waktu dan temperatur serta penentuan awal ketebalan sampel untuk selanjutnya dapat diketahui nilai arus, tegangan waktu dan temperature.

2. Method

This research was conducted using a self-designed electroplating tool. A Screw micrometer was used to measure the thickness of the coating. Then to regulate the temperature of the electrolyte solution used heater. The materials used to make nickel acetate solution are nickel plates measuring 60 mm x 30 mm x 0.1 mm, acetic acid solution of 500 ml with a concentration of 10%, and salt 1/2 tbsp or 5 ml. Making nickel acetate was done by dissolving the nickel anode with the help of DC current in a beaker containing acetic acid solution for 4 hours. Here is a picture of the research flow chart:

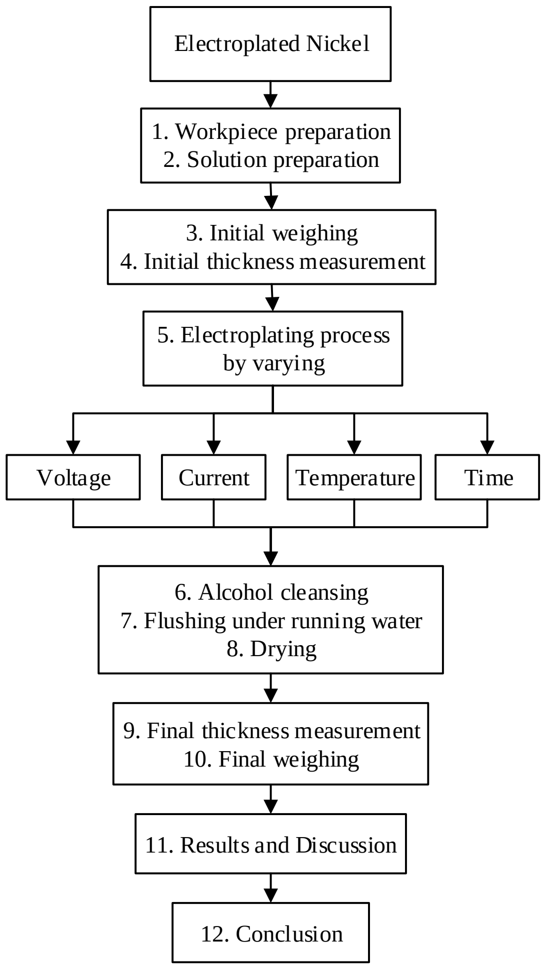


Figure 1. Flowchart research

A research flow chart which includes:

1. Workpiece preparation
   a. Steel cutting with dimensions: length (50mm), width (20mm), and thickness (0.3mm).
   b. Sharpening using sandpaper.
   c. Oil and fat removal using 10% NaOH by soaking for 1 minute.
   d. Surface coral removal using 5% HCL by dipping for 20 seconds.
   e. Pore opening or activating the workpiece by immersion into a 5% H_2SO_4 solution for 20 seconds.
   f. Washing using aquades and finally, drying is carried out.

   Note: At the end of each acid cleaning process, rinsing is done using running water.

2. Solution preparation
   a. Mix 200ml CH_3COOH 25% and 300-ml water.
   b. Adding of 1/2 spoon of salt to increase the conductivity of the solution.
   c. Stirring of the solution is carried out until the solution is homogeneous.
   d. Cut two pieces of nickel with dimensions: length (50mm), width (30mm), and thickness (0.1mm).
   e. Nickel 1, connected to the positive pole, will be the dissolved material and nickel 2, connected to the negative pole.
   f. Then, given a voltage of 5V and a current of 0.5A for 4-5 hours.
   g. Finally, the solution is filtered using filter paper to remove impurities present in the solution.
3. Initial weight weighing using Digital scales.
4. Measurement of the thickness of the initial layer using a screw micrometer.
5. Electroplating using current variations (1A, 2A, 3A, and 4A), voltage variations (3V, 6V, 9V, 12V), temperature variations (30°C, 40°C and 50°C), and time variations (5, 10, 15, and 20 minutes).
6. Steel cleaning using alcohol and Steel rinsing using running water. Furthermore, Steel is dried for 5-10 minutes.
7. Measurement of the thickness of the finish using a screw micrometer. Moreover, weight weighing using digital scales.

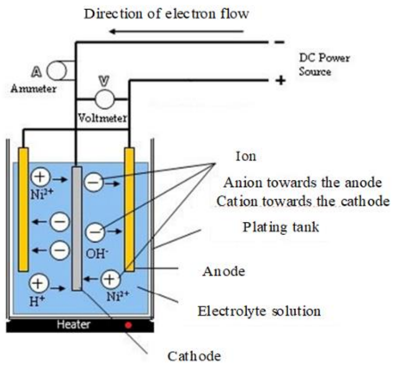


Figure 2. Electroplating System

3. Result and Discussion

In this study, the design of mechanical devices to carry out the electroplating process consisted of anode (nickel), cathode (SK5 steel), heater, beaker, nickel acetate electrolyte solution, and power supply. Fig. 3 is the electroplating system.

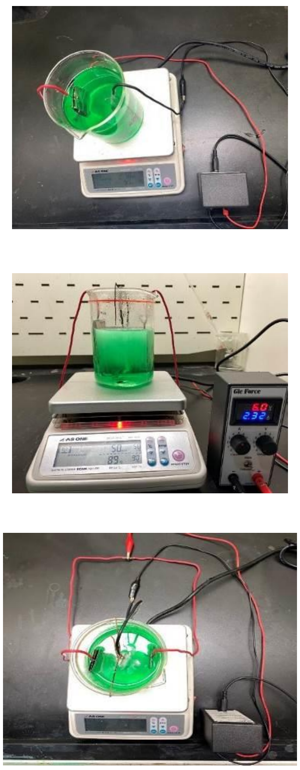


Figure 3. Electroplating system configuration

3.1 Current variation

The current variation was given to electroplating system from 1 A until 4 A with increment 1 A. The result of current variation is shown in TABLE I.

TABLE I. EFFECT OF CURRENT VARIATION

S	**C (A)**	**Thickness (mm)**				
		Initial	**5 m**	**10m**	**15 m**	**20 m**
A	1	0	0	0,01	0,02	0,03
B	2	0	0,01	0,02	0,03	0,04
C	3	0	0,01	0,03	0,05	0,07
D	4	0	0,02	0,04	0,07	0,09

(Detail Information : S (sample), C (Current), and m (minutes))

Tabel 1 gives information about the effect of current variation (1A , 2A, 3A, and 4A) on thickness of the sample. Generally, the thickness of the sample increase with the increment of current. On the other hand, the sample's thickness also escalates with time. The highest sample thickness is sample D with the electroplating time of 20 minutes. Whilst the lowest sample thickness is sample A with the electroplating time of 5 minutes. The sample's thickness raised around 0,01 mm every 5 minutes for sample A and B. On the other hand, the sample's thickness raised around 0,02 mm every 5 minutes for sample C and D.

In conclusion, the sample thickness is affected by current and holding time in this research. This phenomenon is appropriate with the weight of substances formed. The mathematical formula for correlation between weight with current and time can be seen in equation 1.

$$W = (I.\ t.\ Mw) / n\ F \qquad (1)$$

Where:

W = weight of substances formed (g)

I = current strength used (A)

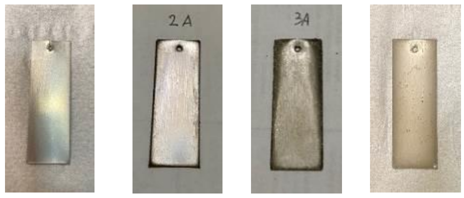
T = time (s)

Mw = molecular weight substances, (g/mol)

N = number of electron involved

F = Faraday number, 96500 C/mol

Based on equation 1, the weight of substances formed positively correlates with the current, time, and molecular weight of substances. Nevertheless, the number of electrons and Faraday number involved are inverse correlation with the weight of substances formed.



A B C D

Figure 4. Electroplating result with variation of time

Figure 4. provides information about the quality of sample surface. Sample D has a good surface quality. It can be seen from the colour distribution, which looks uniformly different from all samples. In addition, this condition is in accordance with the data contained in TABLE I which sample D is the highest thickness sample.

3.2 Voltage variation

The voltage variation was given to the electroplating system from 3 V to 12 V with an increment of 3 V. The result of current voltage is shown in TABLE II.

TABLE II. EFFECT OF CURRENT VARIATION

S	V (v)	Thickness (mm)				
		Initial	5m	10m	15m	20m
E	3	0	0	0,01	0,02	0,03
F	6	0	0,01	0,02	0,04	0,05
G	9	0	0,02	0,05	0,08	0,10
H	12	0	0,03	0,06	0,09	0,11

(Detail Information : S (sample), V(Voltage), and m (minutes))

TABLE II shows the effect of voltage variation on the sample thickness in five holding times in the 3V, 6V, 9V, and 12V.

It is evident that the sample's thickness increased in all five time variations, ranging from 5 to 20 minutes.

Overall, the highest sample thickness was sample H, with a holding time of 20 minutes. Whilst the lowest sample thickness can be seen in sample E, with a holding time of 5 minutes. Furthermore, the thickness of sample escalates when the voltage is increased.

In conclusion, the sample thickness is affected by the voltage and holding time in elctroplating system. This phenomenon is appropriate to law theory. Voltage and current have a linear correlation. The mathematical formula for the correlation between voltage and current can be seen in Equation 2.

$$V = I.R \quad (2)$$

Where:

V = Voltage (V)

I = current strength used (A)

R = Resistance (Ohm)

E F G H

Figure 5. Electroplating result with variation of voltage

The sample surface with voltage variation can be seen in **Figure 5.** Sample H has an even surface distribution with the temperature used at 12 V. The colour of sample H differs from other samples in voltage variation. Consequently, further studies are needed to study the phenomena on the surface of sample H.

3.3 Temperature variation

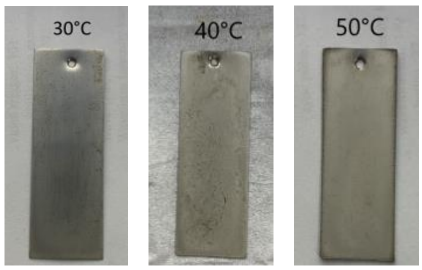
The temperature variation was given to the electroplating system from 30°C to 50 °C every 5 minutes. The result of temperature is shown in TABLE III.

TABLE III. EFFECT OF TEMPERATURE VARIATION

S	°C	Thickness (mm)				
		Initial	5m	10m	15m	20m
I	30	0,00	0,00	0,00	0,01	0,01
J	40	0,00	0,01	0,01	0,02	0,02
K	50	0,00	0,00	0,01	0,03	0,04

(Detail Information : S (sample), C (Current), and m (minutes))

TABLE III shows the effect of temperature variation to thickness of sample every 5 minutes. Generally, the highest sample thickness was sample K with a holding time of 20 minutes. Whilst the lowest sample thickness can be seen in sample I and K with a holding time of 5 minutes. These results have the same condition with current and volatge variation effects on the thickness of the samples. Furthermore, the various of temperatures do not significantly effect with the sample thickness compared with the various current and voltage variations. In conclusion, the thickness of sample is affected by variation of temperature.



I J K

Figure 6. Electroplating results with variation of temperature.

Figure 6 shows the surface of sample for temperature variation**.** It seems that all areas in sample K have an equal distribution of plating. This condition is appropriate with the data in **Table 3.**

3.4 Thickness variation

The thickness variation was given to the electroplating system from 0.03 mm until 0.07 mm with an increment of 0.02 mm. The result of the thickness variation is shown in TABLE IV.

TABLE IV. EFFECT OF THICKNESS VARIATION

S	Thickness (mm)	C (A)	V (v)	°C	Time (m)
L	0,03	0,77	3,0	50	15
M	0,05	1,38	6,0	50	15
N	0,07	2,40	8,5	50	15

(Detail Information : S (sample), C (Current), V (Voltage), and m (minutes))

TABLE IV shows the effect of the thickness variation sample every 0.02 mm. It is clear that when the current and voltage increase, the thickness of samples will rise.

L M N

Figure 6. Electroplating results with variation of temperature.

Figure 6 displays the surface of the sample with thickness variation. Sample L exhibits an equal distribution of plating. However, the thickness of sample N, as the highest thickness samples, cannot be readily identified. Therefore, further investigation is required for sample N.

4. Conclusion

Based on the results, it is concluded that the variations parameter (current, voltage, temperature, and time) affects the thickness of the sample in electroplating process. The current, voltage, temperature and time values have a positive correlation with the thickness in electroplating process. The results obtained are in line with the result of previous research. The further investigation is needed to evaluate the quality of sample's surface.

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