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Effect of Time and Temperature of Electrolyte Solution on Surface Thickness and Hardness Result of Electroplating Nickel on Steel with the Help of a Magnetict Stirrer

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***Abstract*—The nickel electroplating process has been carried out on steel with the help of a magnetic stirrer to homogenize the coating results on the surface. This study aims to determine the effect of time and temperature with the help of a magnetic stirrer on the thickness and hardness of the coating surface. The specimens were coated with 16 ST-37 steel plates with a length of 35 mm, a width of 35 mm and a thickness of 4 mm, and nickel as a coating metal. The thickness of the layer was tested with a stereo microscope and hardness using a hard Vicker test. Sanded the test specimens and cleaned before electroplating process. Coating operation conditions with temperature variations of 40ºC, 45ºC, 50ºC and 55ºC, processing time 10, 15, 20, and 25 minutes, 2 Ampere current, 4 Volt voltage, and 50 rpm magnetic stirrer speed. The results obtained showed that the highest hardness, thickness and mass were obtained at a temperature of 55ºC and time of 25 minutes, namely 242 HV, 112.60 µm, and 0.95 gram. The yield and quality of the layers formed on the surface are strongly influenced by time and temperature. Time and temperature affect the thickness, layer mass, and coating hardness.**

Keywords*—*electroplating, electrolyte, current, thickness, hardness

I. INTRODUCTION

Corrosion that occurs in metals affects the mechanical properties and service life of the material. In order to reduce the corrosive nature of metal-based goods, finishing touches are needed in order to obtain quality goods, more attractive appearance and durable [1]. Coating is an attempt to slow down the corrosion rate of metal surfaces. Metal plating is a method used to give certain properties to a workpiece surface where it is expected that the object will experience repair and resistance and does not rule out improvements in its physical properties [2].

Metallic finishing is a very wide field, an example of which is the electroplating method. Metal electroplating is often used as a means to provide a thin layer on the metal surface of the substrate using metals which have advantages in terms of properties and corrosion resistance [3].

Electroplating is a metal coating on conductive solids with the help of an electric current. The coating is intended to improve the surface of the object so that it is brighter and shinier, corrosion-resistant and the surface of the object becomes tougher, and has certain technical or mechanical properties, and provides decorative value to the base metal [4].

The electroplating process is influenced by the type of material used, time, temperature and the displacement of the atoms themselves. Therefore, it is necessary to use a tool that affects the atomic displacement, one of which is with the help of a magnetic stirrer. By using a magnetic stirrer, which uses a rotating magnetic field to rotate the stir bar, the coating process occurs faster so that the coating thickness on the specimen surface is more even than without a magnetic stirrer.

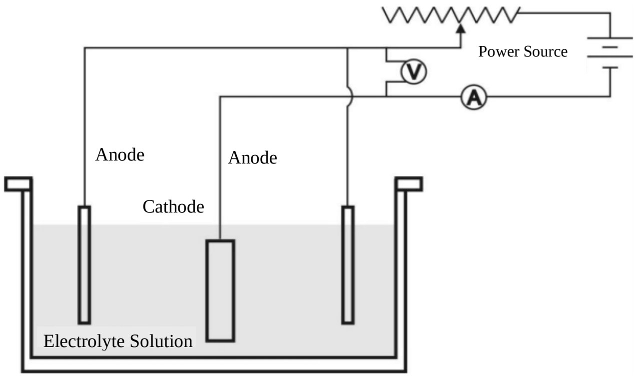


Fig. 1. Basic electrical circuits for electroplating [5].

In metal working technology, the electroplating process is included in the metal finishing process. In the electroplating process, the coated metal functions as a cathode (negative electrode), while the coating metal acts as an anode (positive electrode). In the plating process, current flows from the positive pole to the negative pole while the electron flow flows from the negative pole to the positive pole, using direct current (DC) [6]. The basic circuit of electroplating can be seen in Figure 1.

The mechanism of metal plating starts from the surrounding metal ions by polarizing solvent molecules. Near the cathode surface, an Electrical Double Layer (EDL) region is formed which acts like a dielectric layer. The presence of the EDL layer gives additional burden for the ions to penetrate. With the force of the electric potential difference and assisted by chemical reactions, metal ions will go to the cathode surface, and capture electrons from the cathode while positioning themselves on the cathode surface. In equilibrium conditions after the ions have discharged into atoms, then they will place themselves on the cathode surface by following the atomic arrangement of the cathode material [7].

II. Literature Review

A. Nickel

Nickel is the 24th most abundant element in earth's rocks. Usually nickel is present with iron and cobalt, with characteristic data can be seen in Table 1.

TABLE I. DATA ON NICKEL CHARACTERISTICS [8].

Criteria	Specification
Melting point	1453 ºC
Boiling point	2913 ºC
Atomic mass	58,6934 gr/mol
Density	8,908 gr/cm3
Crystal structure	FCC
Heat of melting	17,48 kJ/mol
Heat of evaporation	377,5 kJ/mol

At present, nickel plating on iron is widely applied both for the purpose of preventing rust or for adding to the beauty of the surface due to the glossy finish. Another type of nickel plating is plating which is black in color. Even this black color looks attractive and is usually used to coat gun barrels and others. Nickel is corrosion resistant, and in its pure state, it is soft, but when combined with iron, chrome, and other metals, it can form tough stainless steels.

Nickel also has moderate hardness and strength, as well as good ductility, electrical and thermal conductivity. Nickel compounds are used primarily as catalysts in electroplating. In the platting process, even though most of the nickel is the anode, you still need to keep adding salt to the platting bath. Salts used for platting include nickel carbonate, nickel chloride, nickel fluoborite, nickel sulfamate, and nickel sulfate. The nickel in the alloy is primarily electrolyzed, the grayish nickel has a face-centered unit cell (FCC). After annealing the tensile strength is 45-55 kgf / mm2, the elongation is 40-50% and the hardness is 80-90 Brinell. Nickel is very good in heat resistance and corrosion resistance, it is not damaged by river water or sea water and alkalis, however nickel can be damaged by nitric acid and slightly corroded by chlorine and sulfuric acids.

B. Carbon Steel

Carbon steel is an alloy of iron and carbon where the carbon element determines its mechanical and physical properties, while other alloying elements act as a support. Carbon is an effective and inexpensive iron hardening element; therefore, a large number of commercial steels contain few alloying elements.

TABLE II. COMPOSITION OF LOW CARBON STEEL ST 37 [9]

Element	Contents (%)
Fe	99.31
Mn	0.375
C	0.118
Si	0.555
W	0.46
S	0.015
Co	0.007
Nb	0.006
Cu	Max 0,004
Mo	Max 0,004

In this research, the steel used is ST 37, where this steel has a tensile strength ≤ 37 kg / mm². ST 37 steel is a low carbon steel, because it has a carbon content of less than 0.3% and more than 99% iron. This low carbon steel is easily oxidized, has relatively low strength, good ductility, and is widely applied to tubes, pipes and low-strength machine components. The composition of ST 37 steel can be seen in Table 2.

III. Research Method

A. *The Materials and Equipment Required*

The materials used in this study were: ST 37 steel plate as a cathode with dimensions of length 35 mm, width 35 mm and thickness of 4 mm as many as 16 pieces. The anodes used were brass (base coat) and nickel with a plating time of 1 minute. Nickel is cut with dimensions of 80 mm x 30 mm and thickness of 1 mm. The electrolyte solution used in plating is electrolyte for plating of brass and nickel.

The equipment used in this study were: Belt sandpaper, Nanofin Polishing, Coating Tub, Thermostat, Stopwatch, Dryer. Digital Balance, Magnetic stirrer. The test tools used for testing the specimen results are: Vicker Hardness Tester and Optical Microscope.

B. *Experimentation*

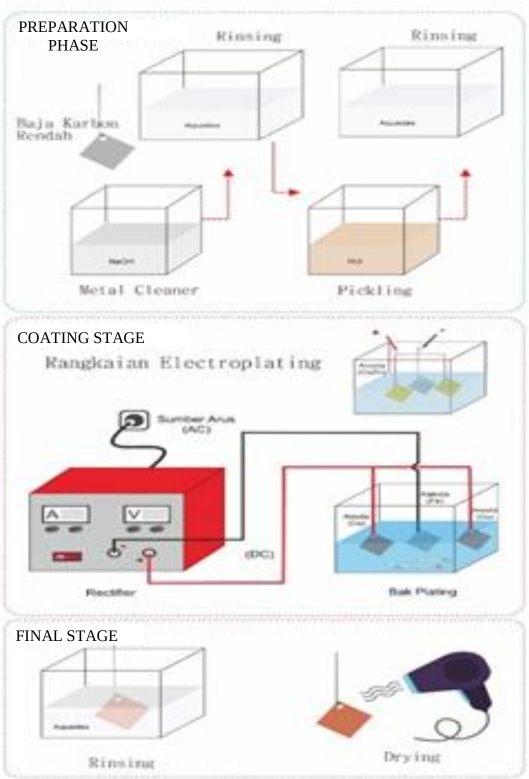


Fig. 2. A series of working stages [10].

Testing is carried out through the following procedures:

1. Specimens are cleaned mechanically with sandpaper and polish. Then proceed with chemical cleaning by dipping in a solution of NaOH, distilled water, HCl and rinsing again with distilled water.
2. The anode is connected to the positive pole of the current source and the cathode to the negative pole of the current source which has been immersed in the electrolyte solution and flows the electric current.
3. Brass plating is carried out at a voltage of 4 volts and a current of 2 amperes in 1 minute.
4. Dipped and cleaned with distilled water.
5. Nickel plating is carried out at a voltage of 4 volts, a current of 2 amperes and a rotation speed of 50 rpm with 4 variations of electrolyte temperature and time:
   - Temperature 39 up to 41°C times 10, 15, and 25 minutes.
   - Temperature 44 up to 46°C times 10, 15, 20 and 25 minutes.
   - Temperature 49 up to. 51°C times 10, 15, 20 and 25 minutes.
   - Temperature 54 up to 56°C times 10, 15, 20 and 25 minutes.
6. Take measurements of hardness, mass, and thickness on the surface of the electroplated specimen.

IV. Results and Discussion

A. *Mass Testing*

From a series of tests that have been carried out, it can be seen that there is an increase in mass with an increase in temperature. The addition of coating mass was calculated by the difference between the initial mass and the mass after the electroplating process. The value of data variation and increase obtained is summarized in graphical form as in Figure 3.

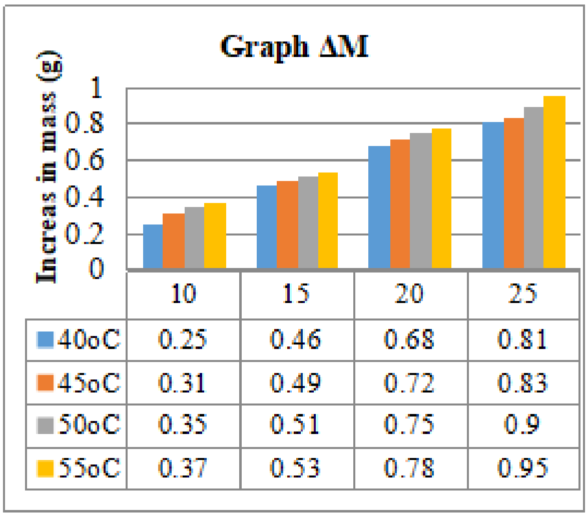


Fig. 3. Graph of the effect of time and temperature on the coating mass.

In Figure 3 it can be seen that the addition of mass is directly proportional to the time and temperature of the electroplating process solution. The value of mass added at temperature variations shows a significant increase in contrast to time variations, where mass gain is more obvious. In accordance with Faraday's law which states that the increased layer mass is affected by the current and the time of the electroplating process [4]. The test results can be seen that the smallest mass gain lies at a temperature of 40ºC and the electroplating process takes 10 minutes, which is 0.25 grams. While the largest mass increase was in the electroplating process for 25 minutes and a temperature of 55ºC, which was 0.95 grams.

In the electroplating process, the use of a magnetic stirrer affects the mass gain. By using a magnetic stirrer, the mass increase value was greater than without using a magnetic stirrer, with the same specimen, namely a temperature of 40ºC. In the 10 minutes variation without a magnetic stirrer, the mass gain value is 0.20 grams, while using a magnetic stirrer with a time variation of 10 minutes the mass gain value is 0.25 grams, this also applies to other time variations [10].

B. Hardness Testing

In the hardness test, 5 test points were taken on the ST 37 steel specimen and nickel plating on the steel. Where is the hardness value of the steel before being coated as in Table 3.

TABLE III. HARDNESS TEST DATA ON STEEL SPECIMENS

Test Point	**Hardness (HVN)**
1	166
2	163
3	164
4	168
5	163
Average	164,8

Figure 4 shows the results of time and temperature variation of nickel-steel coating. The figure shows that the longer the coating time and the higher the temperature of the solution given, the higher the hardness value and this is directly proportional to the increase in the thickness value. At 10 minutes at a temperature of 55ºC, it has a surface hardness value of 196 VHN. Meanwhile, at 25 minutes the hardness value was higher than the coating time of 10, 15 and 20 minutes. This shows that the longer the plating time the more ions are attached to the cathode and the greater the mass that settles according to Faraday's law [11].

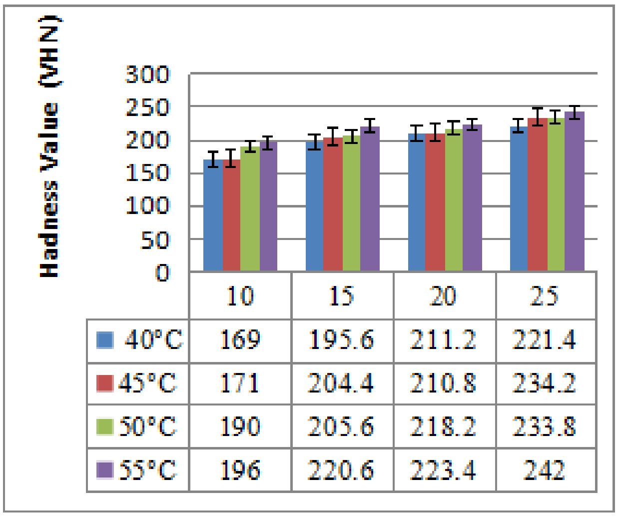


Fig. 4. Graph of the effect of time and temperature on coating hardness.

From Figure 4 it can be seen that the increase in temperature affects the increase in surface hardness of the layer but the increase is not too high. As can be seen in the 10 minute test time at 40 ºC the hardness value is 169 VHN, when the temperature is raised to 45 ºC the hardness value increases to 171 VHN. Likewise for temperatures of 50 ºC and 55 ºC with values of 190 VHN and 196 VHN. This was also experienced in testing by giving variations in time of 15 minutes, 20 minutes and 25 minutes, there was an increase in hardness, but the increase in hardness that was clearly visible was the time variations of more than 20 minutes and 25 minutes. This is because the higher the temperature of the solution usually reduces the absorption of hydrogen in the precipitate, thereby increasing the surface hardness of the layer caused by decreasing the grain size of the precipitate [12].

C. Thickness Testing

The thickness value data collection is done by selecting 3 data points drawn in a straight line (horizontally), the results of the thickness value collection can be seen in Figure 5.

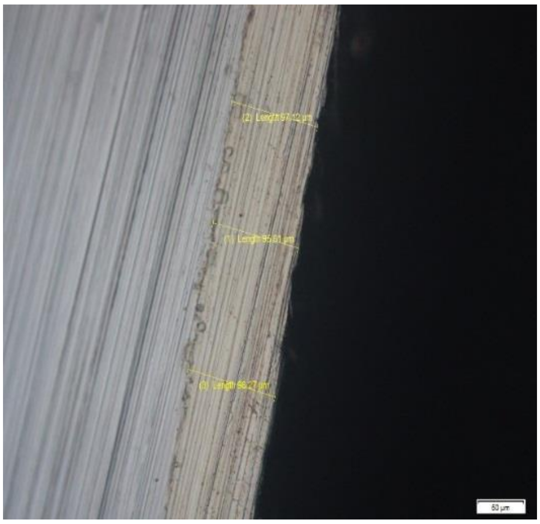
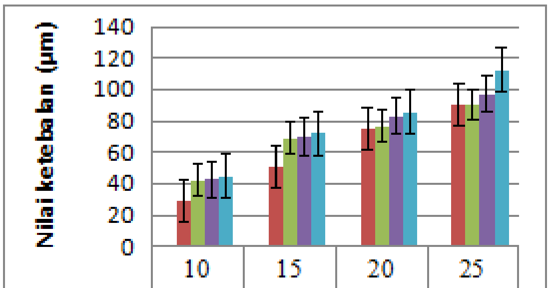


Fig. 5. Result of layer thickness.

Based on the thickness value that has been obtained through testing, it is summarized in graphic data, as shown in Figure 6.



	10	15	20	25
40°C	29.05	50.86	74.61	89.9
45°C	42.28	69.08	76.41	90.21
50°C	42.71	69.85	82.75	97
55°C	44.74	72.19	85.69	112.6

Fig. 6. Graph of the effect of time and temperature on the coating thickness.

Based on Figure 6, it can be seen that the layer thickness value is shown by the dark red bar graph at a temperature of 40°C with a time variation of 10 minutes, 15 minutes, 20 minutes and 25 minutes, the results are respectively 29.05 µm, 50.86 µm, 74, 61 µm and 89.9 µm. The value obtained is much higher with the results of tests that have been done before without a magnetic stirrer with a variation of time 10 minutes, 15 minutes, 20 minutes and 25 minutes, the thickness values are 22.00 µm, 35.53 µm, 41, respectively. 21 µm and 57.93 µm [13]. Likewise, at temperatures of 45°C, 50°C and 55°C the thickness values also increase with the increase in a given temperature. The increase in thickness value with temperature variation has a higher increase when compared to the time variation which can be seen in Figure 6. With the provision of 10 minutes the thickness value increases due to temperature, respectively, between 29.05 µm to 44.74 µm. While the results obtained for the variation of test time obtained an increase in thickness values between 29.05 µm to 112.6 µm.

So the increase in the value of layer thickness is influenced by variations in time, temperature, and the use of a magnetic stirrer. Whereas the variation of the test time is more effective in increasing the value of the layer thickness compared to the variation of temperature, it is in accordance with Faraday's law that the thickness of the layer is affected by the current flow and the coating time [4]. In this electroplating process, it can be seen that the use of a magnetic stirrer affects the thickness, where the thickness value is greater than without using a magnetic stirrer.

The lowest average thickness value is found at a temperature of 40°C with a coating time of 10 minutes is 29.05 µm. And the highest average thickness value is found in the variation of temperature of the 55°C solution with 25 minutes of 112.6 µm.

V. CONCLUSION

From the research conducted it can be concluded that:

- The temperature and time of the electroplating process have an effect on the addition of layer mass. The increase in temperature and coating time used is directly proportional to the increase in mass of the coating formed.
- Magnetic stirrer affects the result of nickel plating on steel. where the coating process occurs faster, and the coating thickness also increases compared to without the use of a magnetic stirrer.
- The value added of mass, hardness and thickness of the layer is directly proportional to time and temperature. The optimum conditions were obtained at 25 minutes, and a temperature of 55°C, namely a mass of 0.95 grams, a hardness of 242 HV, and a thickness of 112.60 µm.

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