Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

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|---|---|---|---|---|---|
| e-ISSN | : 2549-1999 | No. | : 1 | Month | : February |
| p-ISSN | : 1693-5462 | Volume | : 21 | Year | : 2023 |

Received on 2022-10-20, Reviewed on 2022-10-21, Accepted on 2022-11-25, Copy edited on 2023-02-17, Layout edited on 2023-01-30 and Available online on 2028-02-28

# Optimization of nickel electroplating on low carbon steel for corrosion resistance using immersion corrosion test with 3.5% NaCl

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## Abstract
This research studied the corrosion resistance of low carbon steel that has been coated with nickel in NaCl solution by the Immersion Corrosion method with 3.5% NaCl liquid. Coating is done to increase the wear resistance of low carbon steel. The coating is done by electroplating process, with various voltages of 3V, 3.5V, 4V and 5V and the liquid is heated to a temperature of 44-60ºC in the immersion time range of 30 minutes, 40 minutes and 50 minutes for each voltage variation. From the results of the study, it was found that the longer the immersion time in the electroplating process, the thicker the resulting layer with the addition of about 4 8µm for each difference in immersion time.

**Keywords:**
Electroplating, Nickel, Corrosion, Low Carbon Steel

## 1 Introduction
Corrosion is the destruction or damage of material due to reaction with its environment[1–4]. In order to increase the quality of these products, various efforts have been made, one of which is the electroplating method for metal products.

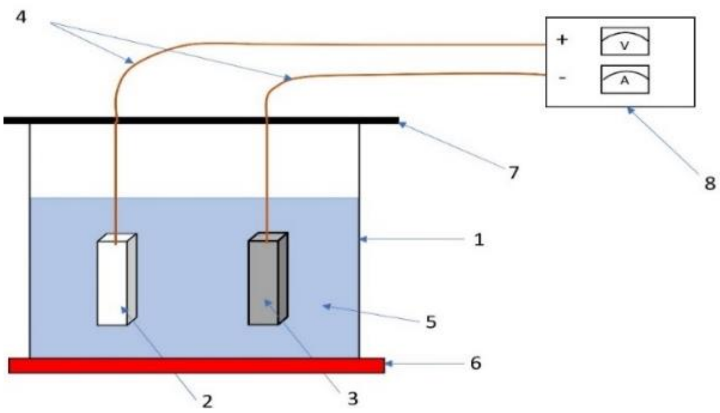
Electroplating aims to coat metal on a metal surface or a conductive surface through an electrochemical or electrolysis process, in order to produce a surface that is resistant to corrosion and improves the quality of appearance in terms of aesthetics[5]. Electroplating can be applied to various metal products such as vehicle frames, vehicle engines, and even household furniture, depending on the needs.

Electroplating uses various materials, such as chromium (Cr), cadmium (Cd), nickel (Ni), copper (Cu), silver (Ag), gold (Au), and others[6-7]. Electroplating using nickel-based materials is used to increase the usability, value, and marketability of goods to consumers and manufactured products. Nickel coating aims to improve physical properties such as wear resistance, heat resistance or corrosion resistance. In many important applications, nickel coatings have the dual role of providing a bright decorative coating and enhancing corrosion resistance or other functional properties[8–10]. Nickel-based electroplating can be applied to workpieces such as steel[11]. Steel is often found in everyday life, for example the frame of a motor vehicle.

Steel is an important part of the modern world[12]. For its use, steel is known to have certain mechanical properties such as hardness[13]. Steel is the main material in the construction of infrastructure, cars, ships, trains, weapons, and tools[14]. Low carbon steel is widely applied to machine parts such as: shafts, screws, chains, gears, and others[13].

In order to improve the quality of products made from low carbon steel raw materials from the manufacturing industry in Indonesia, the author wants to know how to "Optimize nickel electroplating on low carbon steel against corrosion resistance using the immersion corrosion test method with 3.5% NaCl liquid". The author hopes that by doing this research, it can provide input to the manufacturing industry at home and abroad to improve the quality of corrosion resistance of products made from low carbon steel raw materials.

## 2 Research methods
Electroplating is the process of deposition or deposition of coating metal material that wants to electrolyze the workpiece. During the coating process, a chemical reaction occurs at the electrode (anode-cathode) and the electrolyte goes in a certain direction on a regular basis[15-16]. For this to happen, direct current (DC) and a constant voltage are needed. The electroplating process and its components are shown in Fig. 1




| | | |
|---|---|---|
| 1. Vessel | 4. Copper wire | 7. PVC pipe |
| 2. Cathode | 5. Electrolyte solution | 8. Rectifier |
| 3. Anode | 6. Heater | |

Fig. 1. Parts of the electroplating tool

Before carrying out the electroplating process, the main thing to do is cleaning using two stages, namely mechanical cleaning and cleaning using liquid. The mechanical cleaning stage is carried out using a mechanical process that functions to remove scratches on the surface of the specimen as shown in Fig. 2.a low carbon steel specimens used as cathodes and anodes are materials that will coat the specimen or workpiece, the anode is used is pure nickel as shown in Fig. 2b.

(a) (b)
Fig. 2. Anode and Cathode. (a) low carbon steel, and (b) nickel

The cleaning phase using liquid is divided into two types, namely degreasing fluid and activation fluid. The activation fluid used is hydrochloric acid and sulfuric acid which functions to remove oxides or rust, while the alkaline liquid serves to remove oil, grease, and other impurities adhering to the surface of the specimen as shown in Fig. 3a cleaning with activation fluid. After all the steps have been completed, the vessel is filled with electrolyte fluid, then the voltage is adjusted to 3.5V, 3V, 4V, and 5V, then the electrolyte is heated to around 55-60˚C. After reaching the desired current and temperature of the electrolyte liquid, the specimen is inserted into the electrolyte liquid which is wrapped around a copper wire. With immersion time for 30 minutes, 40 minutes, and 50 minutes. After the immersion process is complete, the specimen is removed and then dried.

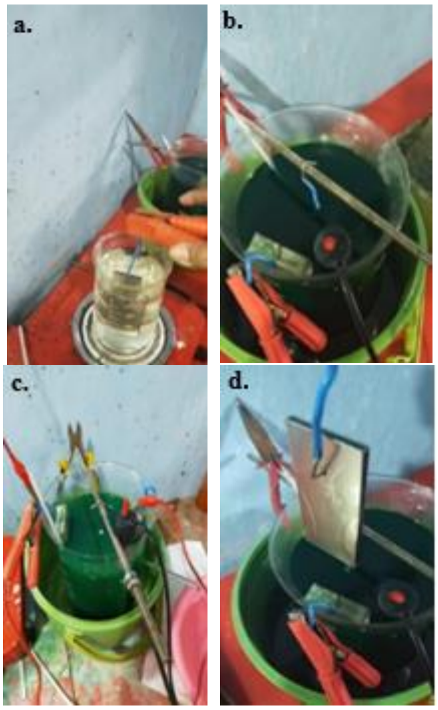



Fig. 3. Electroplating process. (a) cleaning with activation fluid, (b) electrolyte liquid, (c) specimen immersion, and (d) specimen removal

## 2.1 Corrosion testing

One way to determine the corrosion rate of the material is by using the weight loss method or mass loss according to the ASTM G 31-72 standard[17], As expressed by eq. (1), where: K is constant ($8.76x10^4$), W is mass loss (grams), A is surface area ($cm^2$), T is exposure time (hours), and D is specimen density ($gr/cm^3$).

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D} \quad (1)$$

## 2.2 Immersion corrosion test method

The working principle of this method is to dip the specimen into corrosive liquids such as hydrochloric acid, sulfuric acid, nitric acid and other corrosive liquids [18]. This test is carried out on a laboratory scale and can be divided into three methods, namely total immersion test, partial immersion test and wet and dry immersion test.

# 3 Results and discussion

## 3.1. Composition test results

This test uses X-Ray Fluorescence. The following data are obtained from the composition test as shown in table 1.

Table 1. X-Ray Fluorescence Composition Test Results

| | | | | | |
|---|---|---|---|---|---|
| Application | Standardless | | | | |
| Sequence | 1 of 1 | | | | |
| Measurement time | 01-dec-2020 10:17:07 | | | | |
| Position | 6 | | | | |
| Compound | C | Cr | Mn | Fe | |
| Conc Unit | 0,14% | 0,438% | 0,27% | 98,18% | |
| Compound | Cu | Zn | Rb | La | Re |
| Conc Unit | 0,13% | 0,03% | 0,67% | 0,01% | 0,1% |

From the data above, it shows that the specimen that has been tested is a composition of low carbon steel. This is because the carbon element contained is 0.14% so that the specimen falls into the category of low carbon steel. However, there are other elements contained in this specimen, namely 0.438% chromium (Cr) and 0.27% manganese (Mn) which means this specimen has poor hardness and wear resistance due to the standard values of chromium and manganese elements to achieve hardness. and good wear resistance is 13% (for elemental chromium content) and 0.3%-0.5% (for elemental manganese content).

## 3.2 Coating thickness test results

Testing of nickel coating thickness on low carbon steel specimens is carried out at the Brawijaya University Laboratory. This test uses the Coating Thickness Gauge TT230 and data collection is carried out at two specimen points, then the average results are taken. Fig. 4 shows a specimen that has gone through an electroplating process with a time-independent variable. Specimen I was electroplated for 30 minutes, specimen II was electroplated for 40 minutes, and specimen III was electroplated for 50 minutes with the same voltage of 3.5V.

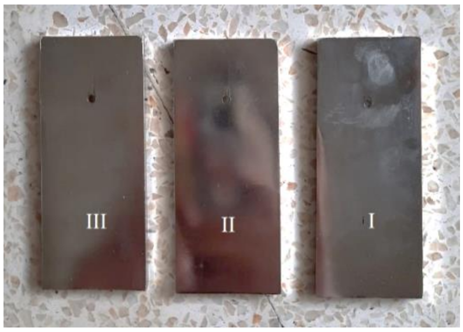



Fig. 4. Specimens after electroplating process independent of time

The result that can be seen directly is that the specimen looks shiny and cleans, but to determine the thickness of the resulting layer, the Coating Thickness Gauge TT230 tool must be used. The data from the coating thickness test can be seen in table 2.

Table 2. Testing data for time-free variable layer thickness

| Independent variable | Test Point | Thickness layer (μm) | Avarage (μm) |
|---|---|---|---|
| 3V | 1 | 189 | 192 |
| 30 minutes | 2 | 195 | |
| 4V | 1 | 193 | 196,5 |
| 30 minutes | 2 | 200 | |
| 5V | 1 | 207 | 208,5 |
| 30 minutes | 2 | 210 | |

From the data in table 2, a graph of the relationship between time and layer thickness resulting from the electroplating process with a voltage of 3.5 V can be drawn as fig. 5.

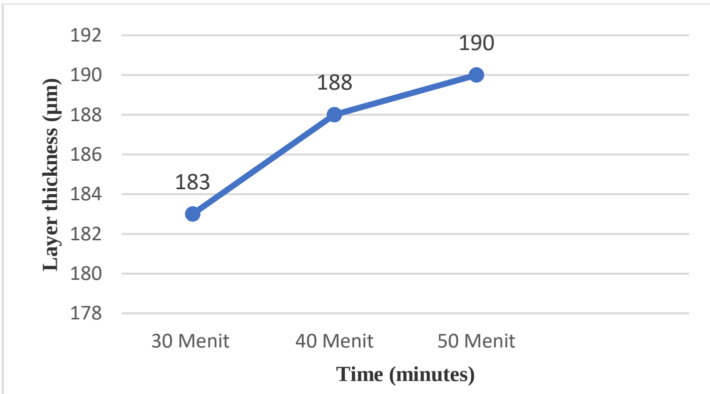



Fig. 5. Graph of the relationship between time and layer thickness

The graph above shows that the duration of immersion during the electroplating process greatly affects the thickness of the coating resulting from the electroplating process. The graph shows that with increasing time the thickness of the layer also increases. The thickness of the resulting layer varies greatly depending on the duration of immersion during the electroplating process, ranging from 183 m in specimen I, 188μm in specimen II, and 190μm in specimen III.

Fig. 6 shows a specimen that has gone through an electroplating process with a voltage-independent variable. Specimen I was electroplated using a voltage of 3V, specimen II was electroplated using a voltage of 4V, and specimen III was electroplated using a voltage of 5V with the same time of 30 minutes.


Fig. 6. Specimens after the electroplating process voltage-independent variable

The result that can be seen directly is that the specimen looks shiny and cleans, but to determine the thickness of the resulting layer, the Coating Thickness Gauge TT230 tool must be used. The data from the coating thickness test can be seen in table 3.

Table 3. Test data of thickness layer with stress-independent variable.

| Independent Variable | Test Point | Layer thickness (μm) | Average (μm) |
|---|---|---|---|
| 3,5V 30 minutes | 1 | 185 | 183 |
| | 2 | 181 | |
| 3,5V 40 minutes | 1 | 188 | 188 |
| | 2 | 188 | |
| 3,5V 50 minutes | 1 | 191 | 190 |
| | 2 | 189 | |

A graph of the relationship between time and layer thickness resulting from the electroplating process with an immersion time of 30 minutes can be drawn as fig. 7.

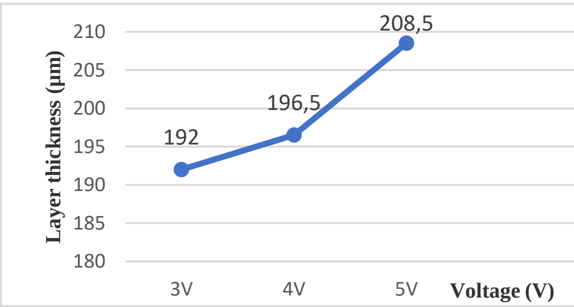



Fig. 7. Graph of the relationship between stress and layer thickness

Fig. 7 shows that the voltage used during the electroplating process greatly affects the thickness of the coating resulting from the electroplating process. The graph shows that with increasing stress, the layer thickness will increase. The resulting layer thickness varies greatly depending on the duration of immersion during the electroplating process, starting from 192 m in specimen I, 196.5 m in specimen II, and 208.5μm in specimen III.

The thickness of this layer is produced because of the electric current in the electrolyte fluid which will cause a chemical reaction. This chemical reaction will cause the deposition of the coating material (anode) on the specimen (cathode), in this case pure nickel acts as the anode and the steel plate specimen as the cathode.

After observing, the results of this electroplating process are not all specimens coated perfectly. As the results of the coating are rough and not smooth, this is due to the lack of cleanliness during the mechanical pre-treatment that uses a grinder and the duration is too long which can cause the coating to become coarse-grained or known as over plate. These rough spots or over plates will cause the coating to become porous, allowing air or other elements to enter.

## 4 Conclusions

From the results of the study, it was found that the longer the immersion time in the electroplating process, the thicker the resulting layer. It can be proved that in specimen I (30 minutes of immersion time) a thickness of 183 m was produced, then in specimen II (40 minutes of immersion time) a thickness of 188 m was produced, and in specimen III (50 minutes of immersion time) a thickness of 190 m was obtained.

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