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# Optimization of electroplating thickness results for SS400 steel using the Taguchi method

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**Abstract**

SS400 steel is steel with a low carbon content (max 0.17 %C) or low carbon steel. SS400 applications are widely used in the construction industry, railway industry, bridges and others. The use of SS400 which is in direct contact with the surrounding environment will cause the appearance, quality, and usefulness of the material or material to decrease. One way to prevent and improve metal performance is electroplating. This study used SS400 carbon steel with chrome coating. The parameters in this study are a voltage of 3, 6, and 9 Volts; the temperature of 45, 50, and 55 $^{o}$C; and the time of 20, 25, and 30 minutes. The Taguchi method L9($3^3$) was used to design the experiments. Analysis of variance (ANOVA) shows that factors of chroming time, voltage, and temperature contribute to coating thickness at the level of 40.615%; 24.951%; and 10.369%, respectively. The maximum thickness of 47.340 µm could be achieved when using combination factors of plating time of 30 minutes, at 9 Volts, and keeping the temperature of the solution at 50 $^{o}$C.

**Keywords:**
SS400 steel, electroplating, chrome coating, Taguchi

## 1 Introduction

As the industry develops and technology and science advance, human life cannot be separated from the use of metals. In engineering, the most commonly used metal is carbon steel. Carbon steel is widely used in engineering applications for construction equipment or materials and accounts for about 85% of annual steel production worldwide. It is also used for a variety of everyday life applications, such as reinforced concrete, underground pipes, bridge construction, petroleum industry and others [1]. Carbon steel has mechanical properties that are easily forged or formed and also has a good hardness value and the price is relatively cheap when compared to other types of metals [2]. Low carbon steels are among the frequently used ones. Low carbon steel is steel that has a carbon level of less than 0.3%. This type of steel is more widely used because low carbon steel has high durability. However, their hardness is low and not good at wear resistance [3]. One example of low-carbon steel is SS400 steel.

SS400 steel is low carbon steel with low carbon content (max 0.17 %C). It has good tenacity properties, moderate hardness, and little silicon content [4]. SS400 steel material can neither be hardened nor heat treated through tempering and quenching processes. SS400 steel can only be set by surface hardening like carburizing [5]. One of the disadvantages of carbon steels is that they are easy to corrode if left in the air and finally the metal is easily porous. This incident occurs continuously if no control and prevention is carried out [1]. Prevention and improvement of metalwork performance are usually done by coating metal using paint, powder coating, heat treatment of metal surfaces, and the addition of solutions. The metal coating is one of the manufacturing processes in an industry at the most common finishing stage for corrosion prevention [6]. To improve the protective and decorative properties of the product and ensure the reliability and durability of metal devices in various operating conditions, it is very important to apply electrochemical or electroplating. Electroplating methods, particularly with chrome coatings, are widely used in mechanical components and instrument manufacturing [7].

Electroplating is the process of moving metal ions with the support of a DC electric current through an electrolyte solution so that the metal ions settle on the solid object to be coated. Metal ions are obtained from electrolyte solutions or come from dissolving metal anodes in the electrolyte solution. Deposition occurs in specimens that act as cathodes [8]. The reaction that occurs in the anode is oxidation, the metal dissolves into the electrolyte and forms positive ions, while the electrons will move towards the cathode through the outer circuit. The positive ions formed to enter the electrolyte solution are in equilibrium with the negative ions moving towards the cathode [8]. While the reaction that occurs at the cathode is reduction. At the cathode, the positive ions will receive electrons derived from the solution of the sharpening metal salt, and the metal will be attached to the cathode more and more. Until it forms a layer that covers the entire surface of the cathode. An electrical layer process requires an electrolyte solution which is the medium of the process taking place [9]. Electrolyte solutions can be made from a solution of acids and metal salts containing positive ions. Electroplating coating has high cleanliness compared to oil paint or spray [10]. Many coatings can be used for electroplating one of them is chrome [11].

Chrome is a non-ferrous metal that has very prominent properties and can be utilized, namely easily oxidized to form a layer of chrome oxide that is rigid, corrosion-resistant, does not change colour to weather but dissolves in hydrochloric acid, slightly soluble in sulfuric acid, and insoluble in nitric acid. From these properties, chrome is widely used as a compound material in iron metal to increase corrosion resistance, and strength and as a coating [12]. As a coating material, chrome is very attractive, because it has a characteristic silver bluish and deep black colour with a reflection power of 65%, friction resistant, and resistant to heat, except at more than 400 °C. However, chrome has an affinity for low liquids, making it less profitable to withstand the use of lubricants and difficult to paint or solder [13].

Several studies on electroplating with chrome have been carried out. Previous studies using temperature variations of 45 $^{o}$C, 55 $^{o}$C, and 65 $^{o}$C with time variations of 10, 20, and 30 minutes resulted in the highest thickness at 55 $^{o}$C and a time of 20 minutes is 65µm. The thickness with the lowest value at 45 $^{o}$C and the time of 10 minutes is 23 µm. The higher the temperature of the solution, the thickness of the chrome layer increases [10]. Other studies, used voltages of 1.5 volts, 2 volts, 2.5 volts, 3 volts, and 3.5 volts with time variations of 5, 10 and 15 minutes. The highest thickness value is obtained with a voltage of 3.5 volts and a time of 15 minutes. The higher the voltage given, the thickness of the layer increases and the longer the dyeing time, the thicker the layer [11].

Many requirements and parameters in the electroplating process explain that coating is done once without considering other factors will give unsatisfactory results. Some of the electroplating outputs that are the focus of researchers and practitioners include (i) mechanical properties in the form of: adhesion [14][15][16], surface hardness [17][18][19], and tensile strength [20][21]; (ii) physical properties: thickness of the coating result [11][22][23][24] and deposit weight [25][26]. The thickness of the layer is considered the most crucial parameter for measuring electroplating results. Thick deposits are expected to be more durable against corrosion, friction, wear and tear in use. For this reason, it is necessary to determine the most optimal parameters to reduce production costs and get the best results.

The Taguchi method and ANOVA were used to determine the most optimal parameters in this study. The Taguchi method is a statistical method used to determine and correct the influence of parameters on product quality. This method strives to achieve the quality and process of making products well by making the product insensitive to noise factors such as operational conditions, human power, manufacturing tools and materials. Taguchi method as robust design by making products as a result of design from the presence of interference factors (noise) [27]. The Taguchi method is very suitable for this study because this study involves many parameters and levels. The advantage of this Taguchi method is that the efficiency of the experimental design is higher because it can conduct research involving many factors and levels, and get consistent product results against interference from factors that cannot be controlled [28]. The Taguchi method offers a very significant reduction in the number of experiments. Compared to the full factorial design (FFD) method, Taguchi's design reduced the number of experiments from 288 to 16 only [29]. Other research proves Taguchi saves the number of experiments up to 89% [30].

The purpose of this study was to find out the influence of temperature, voltage, and time parameters on the thickness of the layer. Then, find a combination of the three parameters that will produce the maximum thickness.

## 2 Methods

a. Time and Place of study

The study was conducted at the Packaging Laboratory of the Faculty of Engineering, Department of Mechanical Engineering, the University of Jember. These activities include the procurement of materials measurement specimens, coating processes, and surface thickness testing. The study process was conducted from January to May 2021.

b. Tools

The tools used in this study were digital scales, Olympus BX41M 33M microscope (UMSP 4), container, rectifier, measuring cup, wire brush, camera, hacksaw, cleaning solution reservoir, barrel, grinding, hand drill, heater (thermal control), alligator clip, gloves and masks, stopwatch, vacuum sucking pipette.

c. Materials

The materials used in this study were SS400 steel as a cathode and chrome as a coating or anode. Autosol is used to refine specimens and remove impurities. Aquades, HCl and NaOH are used to chemically clean specimens. The solution used is a hard chrome solution consisting of $CrO_3$, $H_2SO_4$, and $Na_2SiF$.

d. Data Retrieval

Specimen manufacturing for electroplating process measuring 40 mm × 60 mm × 8 mm with preparation standards using ASTM B-487 – 85 [31]. Each combination is performed 3 times replication. The dimensions of the specimen size are shown in Fig. 1.

**e.** Study Implementation

The implementation of this study is carried out following the flowchart in Fig.. 2

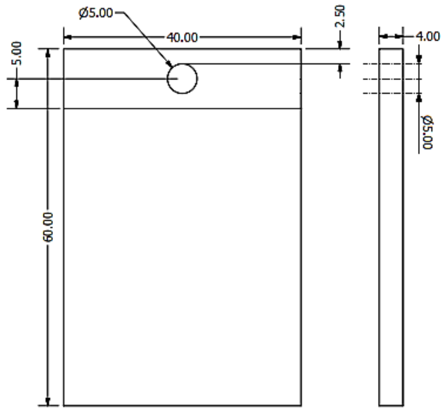


**Fig. 1.** Specimen size dimensions

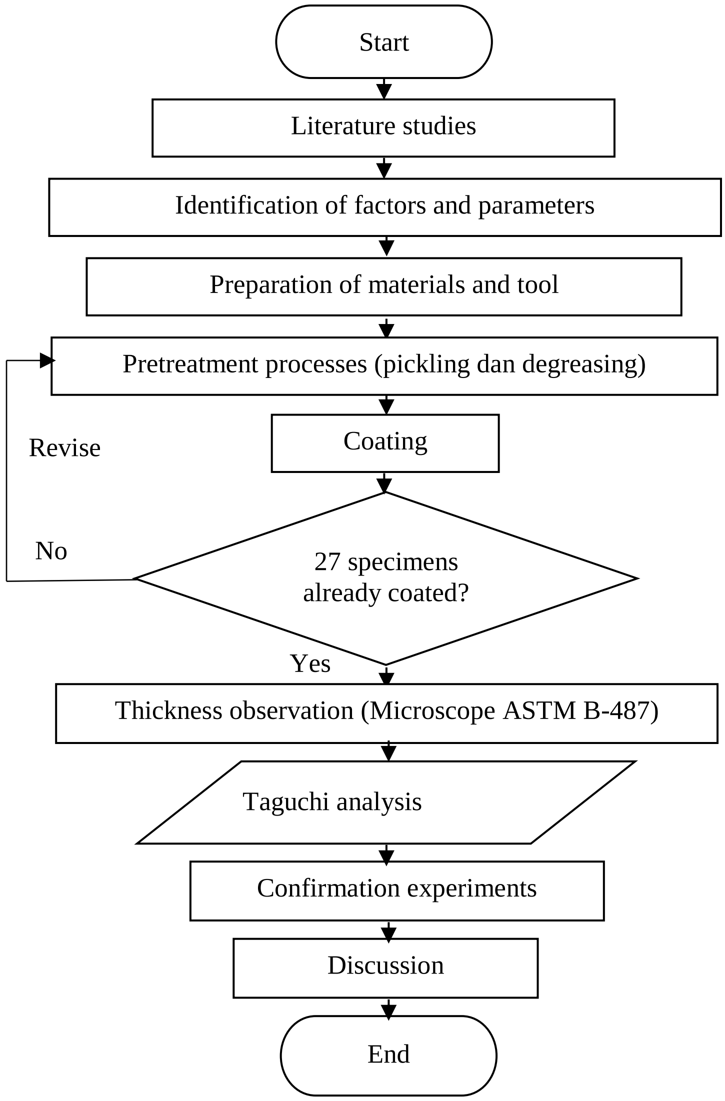


**Fig. 2.** Flowchart of study process

f. Thickness Testing Process Steps

Before the observation using a microscope to see the thickness value, the specimen preparation is carried out first with the following steps.

1. The mounting process is used to prevent side unevenness to be tested. So the surface must be coated to cover the space between the layers with the microscope using resin.
2. Grinding and polishing process to keep the cross-sectional surface perpendicular to the layer. Time and pressure must be maintained so that the limit of the test object can reach a thickness of 10 µm.

3. Process of grinding test specimens on appropriate abrasive paper and using water lubrication. Provide minimum pressure to avoid surface bevelling. Early grinding uses 100 or 180-grade abrasive paper, then uses 240 or 500 grades, and lastly uses 600 grades with a time of 30 to 40 seconds each.
4. Etching is used to remove traces of the metal polishing process.

After preparing the specimen then a thickness test is carried out with the following steps.

1. Testing was carried out on a micrometer filler type or micrometer eyepiece with observations on the coating layer with base metal;
2. Testing is carried out at 3 different points on one specified side;
3. Micrometer testing was calibrated before and after measurement;
4. Observations at one point were made twice;
5. Different results on two tests, taken larger ones;
6. External factors that can affect observation results such as light sources and movements during measurements can be minimized by making observations quickly and measuring each interval twice, once from left to right and from right to left;
7. The limit of resolution is the minimum distance that must be separated between the specimen and the observation hole to determine the desired magnification with optimal display results;
8. Maximum magnification of 100 ×.

g. Analysis Methods

The experimental design used in this study uses the Taguchi method orthogonal array L9($3^3$) which has a combination of 3 parameters and 3 levels of each parameter as shown in table 1 below.

**Table 1**. Parameter dan level used for experimentation

| Control factor | Parameter | lower level | Mid Level | Upper Level |
|---|---|---|---|---|
| **A** | Voltage (volt) | 3 | 6 | 9 |
| **B** | Temperature(°C) | 45 | 50 | 55 |
| **C** | Time (minute) | 20 | 25 | 30 |

The analysis method used in this study was the Analysis of Variance (ANOVA). Data retrieval was taken based on the orthogonal array design of the Taguchi method design. Taguchi's analysis takes the following stages.

1. S/N Ratio
2. Variance analysis
3. Test F
4. Interpretation of experimental results.Interpretation of experimental results consists of per cent contribution of confidence intervals
5. Confirmation experiment

## 3 Results and Discussion

The results of the electroplating process can be seen in Fig. 3. Fig. 3 shows a layer of chrome deposited to the base of the material that has been mounted and prepared before thickness testing using voltage parameters of 9 volts, a temperature of 55 °C, and a time of 25 minutes. The results of the coating surface were taken at 3 points and obtained a thickness of about 45 µm. The same observations were made on all specimens and the results of the thickness test were obtained as shows Table 2.

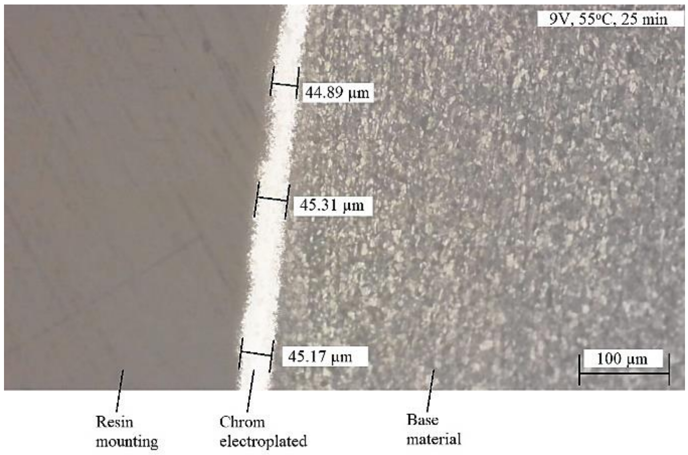


**Fig. 3.** Electroplating process result

**Table 2.** Thickness test results

| Comb. | Control Factor A Vol-tage | Control Factor B Tem-pera-ture | Control Factor C Ti-me | Layer Thickness (µm) I | II | III | Ave-rage | S/N ratio |
|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 45 | 20 | 42.55 | 42.71 | 42.65 | 42,.64 | 32.59 |
| 2 | 3 | 50 | 25 | 43.97 | 44.22 | 44.05 | 44.08 | 32.88 |
| 3 | 3 | 55 | 30 | 45.74 | 45.86 | 45.31 | 45.64 | 33.18 |
| 4 | 6 | 45 | 25 | 44.55 | 44.39 | 44.83 | 44.59 | 32.98 |
| 5 | 6 | 50 | 30 | 46.51 | 46.17 | 46.23 | **46.30** | **33.31** |
| 6 | 6 | 55 | 20 | 44.68 | 44.77 | 44.81 | 44.75 | 33.01 |
| 7 | 9 | 45 | 30 | 46.25 | 46.07 | 46.13 | 46.15 | 33.28 |
| 8 | 9 | 50 | 20 | 45.34 | 45.78 | 45.69 | 45.60 | 33.17 |
| 9 | 9 | 55 | 25 | 45.91 | 45.32 | 45.16 | 45.46 | 33.15 |

Table 2 shows the results of the thickness test with 3 replications of each combination. The S/N ratio used is larger the better because if the thickness value is getting bigger then the result will be better. From Table 2, it can be known that the most optimal coating is found in the 5th combination, that is using a voltage parameter of 6 V, a temperature of 50 °C, and a time of 30 minutes with an S/N ratio of 33.31. The lowest coating results are found in the first combination using voltage parameters of 3 V, temperature 45 °C and time of 20 minutes with a value of S/N ratio 32.59. The average calculation of each level is found in Table 3.

**Table 3**. The average response of S/N ratio values for each control factor

| Symbol | Control Factor | Average Level 1 | Level 2 | Level 3 | Difference |
|---|---|---|---|---|---|
| A | Voltage (volt) | 32.88 | 33.10 | **33.20** | 0.32 |
| B | Temperature (°C) | 32.95 | **33.12** | 33.11 | 0.17 |
| C | Time (minute) | 32.93 | 33.01 | **33.26** | 0.33 |
| | Total Average | | 33.06 | | |

The plot of the average value of the S/N ratio at each level of the coating process thickness parameter voltage, solution temperature, and time is shown in Fig. 4.

From Fig. 4 it can be concluded that the most optimum parameter value indicates the highest S/N ratio value. The combination of levels on the most optimum parameters is shown in the following Table 4.

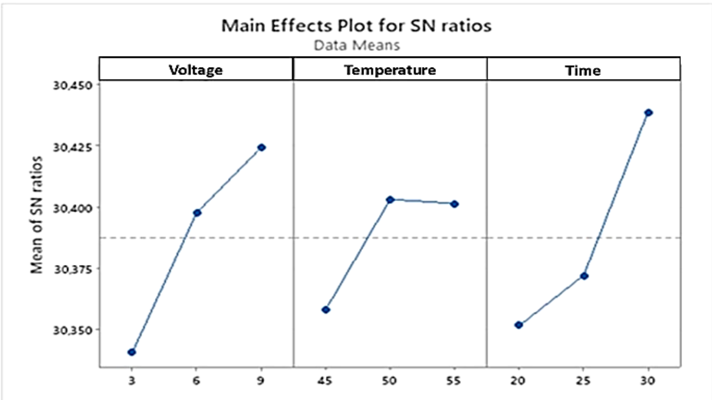


**Fig. 4.** The plot of the average value S/N ratio

**Table 4.** Optimum response layer thickness parameter results

| Symbol | Parameter | Level | Value |
|---|---|---|---|
| A | Voltage (volt) | 3 | 9 |
| B | Temperature ($^{o}$C) | 2 | 50 |
| C | Time (minute) | 3 | 30 |

1. Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is used to find how parameters affect and significantly contribute to layer thickness parameters. In this study, the S/N ratio value was used to calculate the variance analysis that represented the thickness response value. ANOVA calculation was carried out using Minitab 19 trial version and obtained results according to following Table 5.

**Table 5.** Results of calculation of ANOVA control factors on coating

| Parameter | DK | SS | MS | $F_{value}$ |
|---|---|---|---|---|
| Voltage | 2 | 0.156 | 0.0784 | 11.10 |
| Tempe rature | 2 | 0.0562 | 0.0281 | 3.98 |
| Time | 2 | 0.179 | 0.0896 | 12.71 |
| Residual | 2 | 0.0141 | 0.00705 | |
| Total | 8 | 0.406 | | |

In this study, the level of significance used was 5%. The $F_{value}$ obtained above is compared to the $F_{table}$ value of α 0.05 with the degree of freedom [(k-1). (N-k)] with k being the number of levels of the factor while N is the total number of experimental combinations so that the degree of freedom in $F_{table}$ 2;6 is 5.14. The initial hypothesis ($H_0$) and the alternative hypothesis ($H_1$) are used as hypothesis tests using the F distribution as follows:

a. Voltage (volt)
   $H_0 = \mu1 = \mu2 = \mu3$
   $H_1 = \mu1 \neq \mu2 \neq \mu3$
   Conclusion: $F_{value}$ = 11.10> $F_{table\ (0.05;2;6)}$ = 5.14 then $H_0$ is rejected, meaning that the average voltage control factor of each level is different so that the control factor has a significant influence on the thickness of the layer.
b. Solution temperature ($^{o}$C)
   $H_0 = \mu1 = \mu2 = \mu3$
   $H_1 = \mu1 \neq \mu2 \neq \mu3$
   Conclusion: $F_{value}$ = 3.98< $F_{table\ (0.05;2;6)}$ = 5.14 then $H_0$ is accepted, meaning that the average temperature control factor of each level is the same so that the control factor does not have a significant influence on the value of layer thickness.
c. Waktu (menit)
   $H_0 = \mu1 = \mu2 = \mu3$
   $H_1 = \mu1 \neq \mu2 \neq \mu3$
   Conclusion: $F_{value}$ = 12.71 > $F_{table\ (0.05;2;6)}$ = 5.14 then $H_0$ is rejected, meaning that the average time control factor of each level is different so that the control factor has a significant influence on the thickness of the layer.

2. Per cent Contribution

The per cent contribution of each control factor used in the electroplating coating process is contained in table 6 below.

**Tabel 6.** Per cent contribution of each control factor

| Symbol | Control Factor | SS' | ρ% |
|---|---|---|---|
| A | Voltage | 0.142 | 34.951% |
| B | Solution Temperature | 0.042 | 10.369% |
| C | Time | 0.164 | 40.615% |
| R | Residual | | 14.065% |
| Total | | | 100% |

Predict optimal thickness values based on the average combination of S/N ratio values at each level of the parameter being studied. In Table 3 the combination of levels of each parameter that most affects the optimal thickness value is as follows:

a. Volatge (volt) pada level 3
b. Solution temperature ($^{o}$C) pada level 2
c. Time (minute) pada level 3

The thickness prediction value is calculated using the equation as follows:

$$\hat{\mu} = \gamma_m + \sum_{i=1}^{q} \left(\underline{\gamma_i} - \gamma_m\right) \quad (1)$$

$\hat{\mu}$ =33.066+[(33.204 − (33.066) + (33.125 − 33.066) + (33.261 − 33.066)]
$\hat{\mu}$ = 33.066 + 0.138 + 0,059 + 0.195
$\hat{\mu}$ = 33.458

From the calculation above obtained the average predicted value for the optimal combination of thickness values is 33.458.

Determination of the average confidence interval of the predicted thickness value is calculated based on the eq. 2:

$$N_{eff} = \frac{\text{total number of experiment}}{1+\text{number of degrees of fredoom}} \quad (2)$$

$$N_{eff} = \frac{9\ x\ 3}{1 + (2 + 2 + 2)}$$
$$N_{eff} = 3.857$$
$$CI_p = \sqrt{\frac{F_{(\alpha,1,Ve)} MS_{Res}}{N_{eff}}}$$
$$CI_p = \sqrt{\frac{F_{(0,05,2,6)} 0.00705}{3.857}}$$
$$CI_p = \sqrt{\frac{5.14\ x\ 0.00705}{3.857}}$$
$$CI_p = \pm\ 0.0969$$

With that obtained the value of average trust interval thickness value prediction with a confidence level of 95% is 33.458 ± 0.0969 (33.361 ≤ $\hat{\mu}$S/N ratio ≤ 33.554).

3. Confirmation Experiment

Confirmation experiments use the optimal level of each parameter used in the study, then experiments are conducted on confirmation experiments. The results of the confirmation experiment and the S/N ratio obtained as shown in Table 7 are as follows.

**Table 7**. Confirmation experiment thickness value results

| Experi-ments | Control Factor | | | Thick Ness (μm) | S/N Ratio |
|---|---|---|---|---|---|
| | Volta-ge | Tempe -rature | Time | | |
| 1 | | | | 47.51 | |
| 2 | 9 | 55 | 30 | 46.87 | 33.50 |
| 3 | | | | 47.64 | |
| Average | | | | 47.34 | |

Next is to calculate the confidence interval of the confirmation experiment thickness value, which is as follows:

$$N_{eff} = \frac{\text{total number of experiment}}{1+\text{number of degrees of fredoom}} \quad (3)$$

$$N_{eff} = \frac{9 \, x \, 3}{1+(2+2+2)}$$

$$N_{eff} = 3.857$$

$$CI_{CE} = \sqrt{F_{(\alpha,1,Ve)} MS_{Res} \left(\frac{1}{N_{eff}} + \frac{1}{r}\right)}$$

$$CI_{CE} = \sqrt{F_{(0,05,2,6)} 0,00705 \left(\frac{1}{3.857} + \frac{1}{3}\right)}$$

$$CI_{CE} = \pm 0.146$$

So the confirmation experiment confidence interval with a confidence level of 95% is 33.504 ± 0.146 (33.358 ≤ μ S/N ratio ≤33.650). Fig. 5 shows the interval plot of the experiment prediction and confirmation experiment.

Fig. 5 shows that the confirmation experiment value increased compared to the average predictive value in the variability of the S/N ratio. It means, the data with the most optimal variations, that is a voltage of 9 volts, a temperature of 55 $^{o}$C, and a time of 30 minutes taken from Cl or prediction confidence intervals give a significant influence as evidenced by the average increase of the confirmation Cl value.

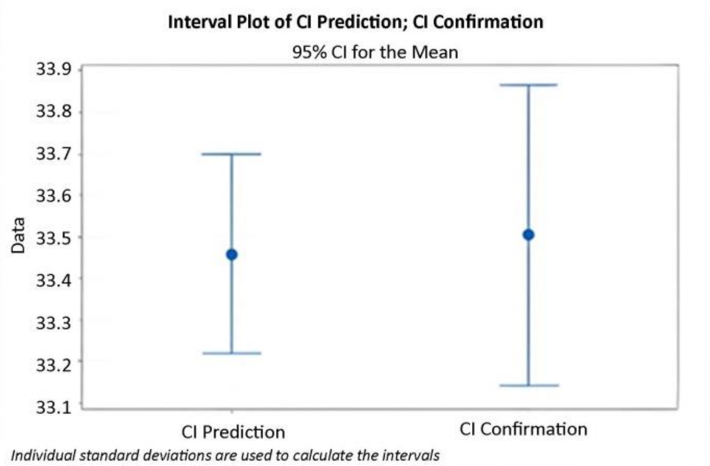


**Fig. 5**. Interval plot of Cl prediction and Cl confirmation

## 4 Discussion

The increase in the value of layer thickness in this study was caused by the large number of ion deposits attached to the workpiece during the electroplating process. The voltage control factor is a controlling factor that affects ionization energy in the electroplating process. The highest thickness value occurs at a voltage of level 3 which is 9 volts as shown in statistical calculations and graphs as the level increases with the thickness value increasing. This is in line with other thickness research [13], where the higher the voltage, the better the coating process. The higher the voltage given, the more reduced chrome ions will be, causing an imbalance between the steel cathode and the chrome anode. From the ion reduction and oxidation reaction, the steel cathode lacks electrons where the higher the voltage then the cathode will need more electrons and the chrome ions released from the anode are also more and more as the voltage exerted increases so that chrome anode in the form of ions fills the steel surface and the coating process occurs causing many chrome ions to detach and settle on the specimen.

The solution temperature is a controlling factor that is convenient for determining the activation energy in the solution. The temperature of the solution that gives the greatest thickness value is at level 2 (50 $^{o}$C) shown in statistical and graph calculations. The activation energy of each metal corresponds to the mass of its atomic type. Chrome material has optimal activation energy for electroplating at a temperature of 50 $^{o}$C. This is following other studies that use temperature parameters of 45 $^{o}$C, 55 $^{o}$C, and 65 $^{o}$C where the most optimal temperature is 55 $^{o}$C and decreases when the temperature is raised to 65 $^{o}$C [10]. If the temperature increases above the activation point it makes many ions be reduced and move more randomly. The colliding chrome ions are reduced so that they are not deposited optimally on the surface of the specimen and cause the thickness value get decrease.

The time control factor is a condition where the ion process undergoes a reduction to oxidation process in units of time. At time 30 minutes, it produces the highest thickness value shown in statistical and graph calculations with a per cent contribution of 40.615%. The same is obtained in other thickness studies [32], that the longer the electroplating time, the more thickness value of the layer increases. This is because the longer the electroplating time, the more and more the process of reduction and oxidation reactions that occur. Over time, chrome ions that undergo a reduction reaction or release of chrome ions in the electrolyte solution are increasing. Then negatively charged chrome ions will require a positive charge so that at the steel cathode SS400 will undergo an oxidation reaction which in chrome ions will be deposited on the surface of the layer. With more time, the deposited chrome ions will increase as the number of chrome ions is reduced to the anode and result in the thickness of the layer increasing.

Other studies on adhesion with the same processes and parameters [15] get the optimal voltage at level 3 which is 9 volts. Similarly in this study, the most optimal voltage is at level 3. This is because the higher voltage will cause the energy to accelerate electrons from the anode to the cathode will be greater and make the element of Cr deposited more and more so that the adhesion value will increase and also the thickness value will be greater. The most optimal temperature in adhesion research is at level 3, which is 55 $^{o}$C. Unlike this study, where the most optimal temperature is at level 2 which is 50 $^{o}$C. This is because at high temperatures the soluble power increases and the decomposition of metal sodium is faster, increasing the mobility of metal ions to deposit and reducing the $H_2$ element that enters the layer. That is, the higher the temperature given, the fewer $H_2$ element that enters the layer will be, then making the adhesion value increase and because fewer $H_2$ elements enter the layer coupled with chrome ions begin to enter the activation point making the thickness value decrease. However, adhesion and thickness studies both have the lowest per cent contribution value of the other parameters. The most optimal time in adhesion study is at level 2 which is 25 minutes. Unlike this study where the most optimal time is at level 3 which is 30 minutes. This is because, in adhesion studies, electrolyte solutions that are often used repeatedly make the resulting dirt more and more which is then mixed into the electrolyte solution and deposited into the workpiece which makes the adhesion value decrease, but the thickness value will increase.

## 5 Conclusion

The results of the analysis using the Taguchi method regarding the optimization of the electroplating process were concluded that:

a. The contributions factors affecting the thickness of the SS400 electroplating result layer with chrome sequentially are process time (40,615%), voltage (34.951%), and temperature (10.369%)
b. A maximum thickness of 47,340 μm is obtained if electroplating using a combination of 9-volt parameters, 50 oC solution temperature and 30 minutes coating time.

## References


[1] N. Ali, T. E. Putra, Husaini, V. Z. Iskandar, and S.Thalib, "Corrosion Rate of Low Carbon Steel for Construction Materials in Various NaCl Concentrations Corrosion Rate of Low Carbon Steel for Construction Materials in Various NaCl Concentrations," in *International Conference on Science and Innovated Engineering (I-COSINE)*, 2019, pp. 1–6. doi: 10.1088/1757-899X/536/1/012015.

[2] ASM International, *ASM Metals HandBook Volume 1 - Properties and Selections - Irons Steels and High and Performance*, vol. 2. 2001. [Online]. Available: http://books.google.com.hk/books?id=eC-Zt1J4oCgC

[3] MatWeb, "Overview of materials for Low Carbon Steel," *MatWeb Material Properties*, 2022. https://www.matweb.com/search/DataSheet.aspx?MatGUID=034970339dd14349a8297d2c83134649&ckck=1 (accessed Apr. 14, 2022).

[4] MatWeb, "AISI 4340 Steel, annealed, 25 mm round," *MatWeb Materials Properties*, 2022. http://www.matweb.com/search/DataSheet.aspx?MatGUID=fd1b43a97a8a44129b32b9de0d7d6c1a&ckck=1 (accessed Apr. 11, 2022).

[5] V. M. Pratiwi, "Study of AISI 1020 Steel Characterization By Zinc- Electroplating Treatment," *Mater. Res. Commun.*, vol. 1, no. 1, pp. 34–41, 2020.

[6] R. Riastuti, F. Herdino, A. Rifki, C. Ramadini, and S. T. Siallagan, "The effect of sodium citrate as an additive on properties of electroplated nickel on SPCC steel," *AIP Conf. Proc.*, vol. 2043, 2018, doi: 10.1063/1.5080032.

[7] H. H. Lou and Y. Huang, "Electroplating," in *Encyclopedia of Chemical Processing*, Taylor & Francis, 2006, pp. 1–10. doi: 10.1081/E-ECHP-120007747.

[8] N. A. Hamza, A. S. Majeed, and S. M. Jawd, "Review on Types and Methods of Electroplating on Metals," *J. Power Electron. Devices*, vol. 7, no. April, pp. 44–51, 2021, [Online]. Available: https://www.researchgate.net/publication/350872502

[9] A. M. Lazarenkov, "A study of working conditions in electroplating shops," *Foundry Prod. Metall.*, no. 3, pp. 160–162, 2019, doi: 10.21122/1683-6065-2019-3-160-162.

[10] A. S. Pamungkas, H. Prasetyo, and N. Mulyaningsih, "Pengaruh Variasi Temperatur Elektroplating terhadap Ketebalan Lapisan Nikel Baja ST37 Grafik Hubungan Temperatur dan Tebal Nikel," *MER-C*, vol. 1, no. 2, pp. 3–5, 2018, [Online]. Available: http://jom.untidar.ac.id/index.php/merc/article/viewFile/121/pdf

[11] Paridawati, "Analisa Besar Pengaruh Tegangan Listrik terhadap Ketebalan Pelapisan Chrome Pada Pelat Baja dengan Proses Electroplating," *J. Ilm. Tek. Meisn*, vol. 1, no. 1, pp. 36–44, 2013, [Online]. Available: https://media.neliti.com/media/publications/97467-ID-analisa-besar-pengaruh-tegangan-listrik.pdf

[12] D. T. Ngon, L. C. Cuong, and N. V. Phoi, "Study of the Effect of Chrome Coating Layer to the Fatigue Strength of the Axial Machine Parts," in *Proceedings - 3rd International Conference on Green Technology and Sustainable Development, GTSD 2016*, Dec. 2016, pp. 135–140. doi: 10.1109/GTSD.2016.40.

[13] A. Saleh, *Teknik Pelapisan Logam dengan Cara Listrik*. Bandung: Yrama Widya, 2014.

[14] N. G. Furqon and S. Sulistijono, "Pengaruh Densitas Arus dan Waktu Kontak Efektif Elektrolit Gel terhadap Ketebalan dan Kekuatan Lekat Lapisan Krom pada Baja dengan Metode Elektroplating," *J. Tek. ITS*, vol. 4, no. 1, pp. F134–F139, 2015, [Online]. Available: http://ejurnal.its.ac.id/index.php/teknik/article/view/9138

[15] M. Darsin, A. A. Rosyadi, P. R. Kurniawan, and M. S. Hussin, "Optimization of adhesive strength of chrome coating of SS400 using Taguchi method," *Adv. Eng. Sci.*, vol. 54, no. 01, pp. 947–959, 2022, [Online]. Available: https://www.gkyj-aes-20963246.com/article/optimization-of-adhesive-strength-of- chrome-coating-of-ss400-using-taguchi-method

[16] C. H. Seah, S. Mridha, and L. H. Chan, "Adhesive strength of electroplated copper films," *J. Mater. Process. Technol.* , vol. 114, pp. 252–255, 2001.

[17] A. Rasyad and B. Budiarto, "Analisis Pengaruh Temperatur, Waktu, dan Kuat Arus Proses Elektroplating terhadap Kekuatan Tarik, Kekuatan Tekuk dan Kekerasan pada Baja Karbon Rendah," *J. Rekayasa Mesin*, vol. 9, no. 3, pp. 173–182, 2018, doi: 10.21776/ub.jrm.2018.009.03.4.

[18] M. Y. Niam, H. Purwanto, and S. M. B. Respati, "Pengaruh Waktu Pelapisan Elektro Nikel-Khrom Dekoratif terhadap Ketebalan, Kekerasan dan Kekasaran Lapisan," *J. Momentum*, vol. 13, no. 1, pp. 7–10, 2017.

[19] R. Usman, "Pelapisan Baja dengan Logam Chrom terhadap Kekerasan Permukaan Melalui Proses Elektroplating," *Polimesin*, vol. 1, no. 1, pp. 67–70, 2004, [Online]. Available: http://e-jurnal.pnl.ac.id/polimesin/article/view/1402

[20] T. Mulyanto and Mulyuda, "Analisi Sifat Mekanis pada Baja SS400 akibat Pengaruh Tebal Lapisan Chrome dengan Metode Elektroplating," *J. Tek.*, vol. 30, no. 1, pp. 22–27, 2017.

[21] M. S. Amin, M. Darsin, and A. Sanata, "Optimasi Kekuatan Tarik Proses Electroplating SS400 Menggunakan Metode Taguchi," *J. Ris. Teknol. Ind.*, vol. 14, no. 1, p. 54, 2020, doi: 10.26578/jrti.v14i1.5839.

[22] Ndariono, "The influence of the temperature of electrolyte, cathode current density about the thickness and the adhesiveness in electroplating process of copper-nickel-chromium," University of Sebelas Maret Surakarta, 2011. [Online]. Available: https://eprints.uns.ac.id/2327/1/207751111201104461.pdf

[23] I. Ansari, B. Indrawijaya, F. Nurohmawati, I. Zakaria, S. Kimiauniversitas, and A. Zinc, "Pengaruh Waktu dan Luas Permukaan terhadap Ketebalan Produk pada Elektroplating Acid Zinc (Study of Impact Time and Surface Area to Thickness at Electroplating on Acid Zinc)," *J. Ilm. Tek. Kim. UNPAM*, vol. 1, no. 1, pp. 1–7, 2017, [Online]. Available: http://openjournal.unpam.ac.id/index.php/JITK/article/viewFile/522/426

[24] A. H. K. Harsito, I. S. Aisyah, D. Daryono, A. Saifullah, H. Hendaryati, and S. Sudarman, "The Effect of Agitation Parameter on Hardness and Thickness of Decorative Nickel-Chrome Coating on A36 Steel using Electroplating Process," *J. Energy Mech. Mater. Manuf. Eng.*, vol. 5, no. 2, p. 47, 2020, doi: 10.22219/jemmme.v5i2.13726.

[25] M. A.B. and R. Kurniawan, "Pengaruh Temperatur

dengan Konsentrasi Elektrolit terhadap Hasil Elektroplating Tembaga pada Baja Karbon Rendah," *Polimesin*, vol. 3, no. 2, pp. 229–235, 2005, doi: http://dx.doi.org/10.30811/jp.v3i2.

[26] Yuniati, "Pelapisan Baja Menggunakan Logam Nikel sebagai Penghambat Laju Korosi Baja Melalui Proses Elektroplating," *Polimesin*, vol. 2, no. 1, pp. 95–98, 2004, [Online]. Available: http://e-jurnal.pnl.ac.id/polimesin/article/view/1406

[27] K. Krishnaiah and P. Shahabudeen, *Applied Design of Experiments and Taguchi Method*. New DelhI: PHI Learning Private Limited, 2012.

[28] M. Kowalczyk, "Application of Taguchi and ANOVA methods in selection of process parameters for surface roughness in precision turning of titanium," *Adv. Manufactucturing Sci. Technol.*, vol. 38, no. 2, 2014, doi: 10.2478/amst-2014-0008.

[29] Y. A. Youssef, Y. Beauchamp, and M. Thomas, "Comparison of a Full Factorial Experiment to Fractional and Taguchi Design in a Lathe Dry Cutting Operation," *Comput. ind. Engng.*, vol. 27, no. 94, pp. 59–62, 1994.

[30] M. N. Islam and A. Pramanik, "Comparison of Design of Experiments via Traditional and Taguchi Method," *J. Adv. Manuf. Syst.*, vol. 15, no. 3, pp. 151–160, 2016, doi: 10.1142/S0219686716500116.

[31] ASTM, *Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of Cross Section. American Society for Testing and Material*. Philadelphia: ASTM, 2013.

[32] A. S. Darmawan, I. D. K. Okariawan, and N. H. Sari, "Pengaruh Variasi Kuat Arus Listrik dan Waktu Proses Electroplating terhadap Kekuatan Tarik, Kekerasan dan Ketebalan Lapisan pada Baja Karbon Rendah dengan Krom," *Din. Tek. Mesin*, vol. 5, no. 2, pp. 66–71, 2015.