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Optimization of Electroplating Thickness Quality at Hip Joint Implant using the Taguchi Method

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ABSTRACT

The hip joint is one of the most often used joints by humans in their activities. The hip joint can be impaired if an accident or an illness such as osteoarthritis-affected. It makes the patients need to get implants to restore their productivity. The implant must be biocompatible, bioactive, and have high strength and resilience to prevent damage. The implants in this study were made from 304 Stainless Steel. One of the stages in making implants is the electroplating process. The electroplating method implemented is hard chrome. Some operating conditions that affect the electroplating process and are used as independent variables are the concentration of chromic acid, electrical voltage, and length of coating time. This study aims to Optimization of Electroplating Thickness Quality at Hip Joint Implant. This study uses the Taguchi method to design the experiment and to obtain the optimum electroplating thickness results. ANOVA is used to obtain the effective prediction of the significance level. Process ANOVA was helped Minitab 16. Based on the ANOVA, it is known that the most significant factor for the electroplating thickness is the concentration of chromic acid, the voltage, and the least influential factor is the electroplating time.

1. Introduction

According to WHO, in 1997, health is a complete physical, mental, and social condition. It is also a state of being free from illness biological, physical, social, and psychological diseases and the risk of diseases that cause death. Humans carry out movements driven by the skeletal system and muscles. The joint that has a significant contribution to physical work is the hip joint. When activities, the hip joint experiences loading determined by skeletal strength, inertia, and gravity [1]. The strength of the peak contact on the hip joint is three times the body weight when walking on the stairs.

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This strength is also more than seven times the body weight during climbing stairs. Therefore, the hip joint becomes the second joint most often affected by osteoarthritis [2]. The hip joint is disrupted in the event of an accident (osteoarthritis). There are 3% of adults who have symptoms of osteoarthritis [3]. It causes harm to the sufferer. Some of these disadvantages include reduced productivity [4]. Sufferers need to get implants to restore the productivity of their owners. Implants must be biocompatible, bioactive, and have high strength and resilience [5].

Implants can be made from ceramics, metals, and polymers [6]. Metal alloys are used for fracture fixation, surgical instruments, bone screws, dental implants. Furthermore, joint replacement uses stainless steel, cobalt-chromium alloys, titanium and titanium alloys, and zirconium alloys. At present, internal stainless steel biomaterials are focused on fracture fixation plates [7]. Stainless steel is generally known for its corrosion resistance. Stainless steel recommended for manufacturing surgical devices is the American Iron and Steel Institute (AISI) type 316L. "L" indicates low carbon content. 316 defines the appropriate metal level to be implanted, which is also called surgical stainless steel [8]. 316L stainless steel, iron, chromium, and nickel ions are believed to have allergic properties. Corrosion can also cause physical changes to the implant, increasing the likelihood of mechanical failure.

Nickel content in SS316L is a problem with implants. Nickel is one of the triggers for allergies. There are 13% of humans who are sensitive to nickel and cobalt [9]. Therefore, it needs an alternative type of stainless steel with lower levels of nickel and cobalt (SS304). According to the material safety data sheet (MSDS), the nickel content in SS316L is 10-15%, and cobalt is 0-1%. The nickel content in SS304 is 8-10.5% without cobalt content. One of the stages in making implants is the electroplating process. It gives layers to implanted medical devices to reduce friction between the device and human tissue. The advantage of this process is that it has an excellent surface, consistent adhesion, wear resistance, and coating homogeneity [10]. One procedure is to carry out electroplating. This process involves coating a metal with another metal in an electrolyte solution using electric current [11]. The primary material in the electroplating process is usually metal [12]. One method of electroplating is chrome electroplating. It uses chrome as a coating material. This method aims to provide a high level of hardness on the metal surface. It also increases wear resistance, reduces friction, provides non-stickiness, and, in some cases, increases corrosion resistance. Two types of chrome electroplating are hard chrome and thin dense chrome electroplating. Both types of methods have differences in their application [13]. Thin dense chrome electroplating is used in hollow workpieces, while hard chrome is applied to solid workpieces. The form of a solid implant makes this study using the hard chrome electroplating method.

Quality characteristics are highly dependent on the type and function of the implant [6]. Several characteristics such as elasticity, yield stress, tenacity, deformation depending on time, main strength, fatigue strength, hardness, and wear resistance. Some critical variables on the mechanical properties of electroplating include melting rate, material surface preparation, the thickness of electroplating, and arrangement of material compounds [14]. The thickness of the electroplating layer increases The compressive load [15]. It shows the importance of the thickness value of electroplating in preventing implant fractures. Several operating conditions can affect the electroplating process. These conditions are coated material, electricity voltage, length of coating time, and distance between cathode anodes in an electroplating bath [16]. The values of thickness and hardness increase with the increasing value of the electrical voltage used [16]. The thickness and hardness values in the hard chrome layer increase with the increase in electricity voltage and electroplating coating time [17]. Other studies showed

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that the concentration of chromic acid is inversely proportional to throwing the power of brass material [18].

Several related studies have been carried out. However, this study uses different experimental parameter values. This study investigates the factors that influence and optimize each parameter to obtain optimal implant electroplating results. The experiment was carried out by the Taguchi method. It provides a preliminary plan in an orthogonal array (OA) which provides a combination of parameters and different levels of each experiment [19]. The author conducted a study on optimizing the electroplating process using chrome on the hip joint implant made from SS304 using the Taguchi method. Investigated parameters were carried out to know the effect of electroplating time, voltage, and chromic acid concentration on the electroplating process. Moreover, the thickness of electroplating in hip joint implants is optimized.

2. Methods

This research is divided into several stages: material, experimental procedure, experimental design, and data analysis. The detailed steps are described as follows:

2.1 Material

The test specimens in this study were made from SS304 material. It has ASTME 9-89a Standart with cylindrical shapes 10 ± 0.2 mm in diameter and 25.0 ± 1.0 mm in height. Furthermore, an electrolyte fluid was made from chromic acid and distilled water. Make sure all the machines and supporting parts are ready to use. This preparation is based on the orthogonal array that was made. The surface of the specimen is smoothed using sandpaper.

Furthermore, the specimen is confirmed to be smooth and flat and continues into the test specimen cleaning process. Cleaning is done by detergent to the test specimen to clean the dirt and oil attached to the specimen. Furthermore, the test specimens are rinsed thoroughly, and there is no detergent and residual attached. The measurement of the thickness of the electroplating layer was used microphotographs.

2.2 Experimental procedure

The following are the steps in the electroplating process: 1. Connect the power supply to the source of the electric current; 2. Insert the anode into the electroplating bath: 3. Connect the power supply to the electroplating bath; 4. Enter the ingredients needed to make an electrolyte solution: 5. Insert the test specimen into the electroplating bath; 6. Raise the lever to turn on the power supply; 7. Perform electroplating as many as five replications; 8. Lower the lever to turn off the rectifier; 9. Lift the test specimen out of the electroplating bath 10. Clean the test specimens from the remnants of the solution with clean water; 11. the specimen is dried.

Furthermore, specimens have tested the thickness. It was conducted to determine the microstructure and thickness value of each of the SS304, which has been chrome coated. Testing is done using a micro photo tool. This thickness testing was carried out in the following steps: 1. Place each specimen on a micro photo tool; 2. Perform micro photo test on the test specimen; 3. Record the results of the thickness test values of each specimen.

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2.2 Experimental Design

This research used the Taguchi method. The Taguchi design provides a powerful method for designing experimental for a variety of conditions. Several operating conditions affect the electroplating process. These included the coating material, electrical voltage, length of coating time, and distance between cathode anodes in an electroplating bath [16]. The experiment design begins with the stages of determining the response. The response has used the thickness of the electroplating layer on SS304 specimens.

Furthermore, this research determination of experimental factors that influence the value of electroplating thickness. The factor used in this study is the electroplating time, the amount of chromic acid concentration, and the voltage value. The level of each factor in the experiment is shown in Table 1.

Table 1. Setting the experimental factor level

Factor code	Variable	Level 1	Level 2	Level 3
A	Electroplating time (min)	5	10	15
B	Chromic acid (mol)	100	150	200
C	Voltage (volt)	4.5	6	7.5

The next step is to determine the orthogonal array (OA). It consists of controlled factors and uncontrolled factors. This experiment used three controlled factors with three levels for each factor. Therefore, the degrees of freedom are obtained df = controlled factors x (level − 1) = 6. The OA matrix selected is a matrix with $df > 6$. Therefore, it can condition the experiment for three factors with three levels. Hence, the chosen OA design is L9 (34). The determination of the OA matrix is presented in Table 2.

Table 2. Orthogonal array L9

Experiment Number	Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

2.3 Data Analysis

This data processing is done by analyzing the results of Taguchi. Furthermore, data from the experiment were analyzed using ANOVA. This value is used to get the optimal electroplating thickness value on the SS304 material. ANOVA was used to obtain predictions of the influence of the significance level of Electroplating Thickness. The ANOVA process is assisted by Minitab 16. We also used Signal to Noise (S/N Ratio) to analyze the experimental.

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3. Result and Discussions

The results of the electroplating thickness measurements are shown in Table 3. Fig. 1 and Fig. 2 are the results of the photo micro carried out on the test specimens with experimental 2 and 3. Specimen experiment 2, when electroplating for 5 minutes, the concentration of chromic acid as much as 150 mol, and 6 volts. While the experiment number 3 specimen is electroplating for 5 minutes, the concentration of chromic acid is 200 mol, and the voltage is 7.5 volts.

3.1 ANOVA Analysis

The ANOVA shows the influence of each factor on the test response. From Table 4, it is seen that the three independent variables have a value of P <0.05. three-factor does not have a significant effect on the thickness response value of the electroplating layer. Table 4 shows that the P-value of the chromic acid concentration variable has a significant influence value of 0.0936. The time has a p-value of 0.5564 and the electrical voltage with a p-value of 0.3005. Therefore, the sequence of the most influential factors in this study is the concentration of chromic acid. The second influential electric factors are voltage. The least influence is the time factor of electroplating.

Table 3. Thickness Test Results

Exp No.	Time (min)	Chromic acid (mol)	Voltage (Volt)	Thickness test results (µm)					Average Thickness (µm)
				1	2	3	4	5	
1	5	100	4.5	12.9	12	13.2	9.13	11.2	11.686
2	5	150	6	5.9	3.78	4.84	4.41	4.28	4.642
3	5	200	7.5	7.17	6.46	7.13	4.78	5.5	6.208
4	10	100	6	5.5	6.46	7.45	6.46	6.76	6.526
5	10	150	7.5	13.5	11.8	13.49	10.1	12.5	12.278
6	10	200	4.5	4.54	3.78	5.29	3.78	2.27	3.932
7	15	100	7.5	7.56	11.2	10.2	7.78	13.5	10.048
8	15	150	4.5	3.85	5.5	4.54	4.6	4.78	4.654
9	15	200	6	4.54	3.78	2.27	3.02	3.02	3.326

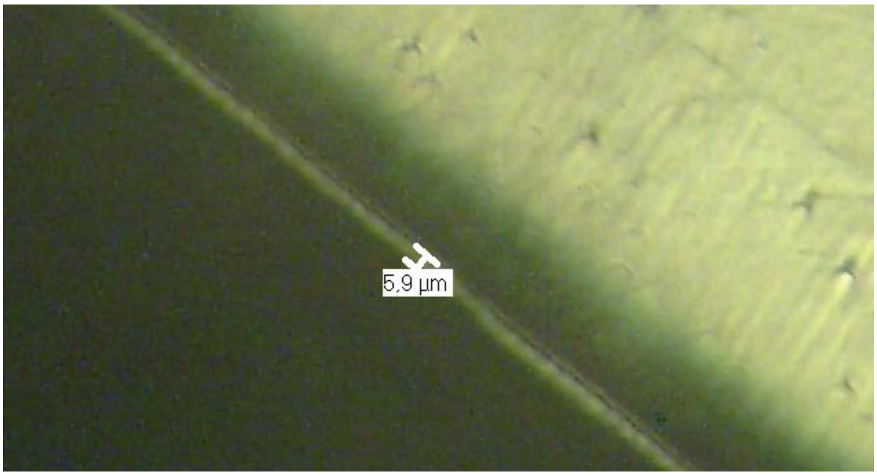

Fig. 1. Results Thickness Test of The Second Specimen Experiments

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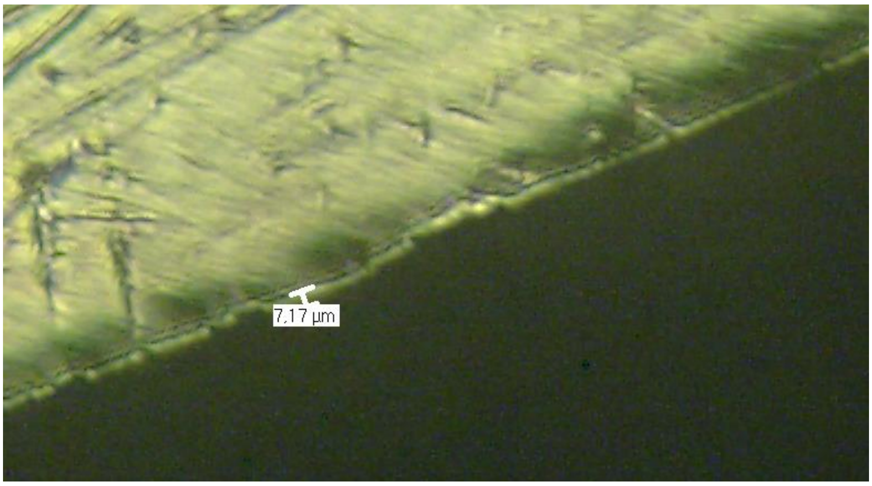

Fig. 2. Results Thickness Test of The Third Specimen Experiments

Table 4. The ANOVA of Electroplating Thickness

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	51.24	3	17.08	2	0.233
A-Time	3.39	1	3.39	0.4	0.556
B-Chromic acid	36.48	1	36.48	4.27	0.094
C-Voltage	11.38	1	11.38	1.33	0.301
Residual	42.68	5	8.54		
Cor Total	93.92	8			

3.2 S/N Ratio Processing

The data experimental was transformed into the form of the S/N ratio. It is carried out to find out the factors that influence the thickness response. Table 5 shows the result of calculating the value of the S / N ratio for thickness response through various levels from each independent variable.

Table 5. S/N Ratio of Thickness Response Electroplating

Level	Time	CA	Voltage
1	7.512	9.42	6.757
2	7.579	7.191	4.831
3	6.009	4.489	9.511
Delta	1.569	4.931	4.680
Rank	3	1	2

Fig. 3 shows that the value of thickness increases at the electroplating time of 10 minutes. However, it decreases when the electroplating time exceeds 10 minutes. The decreased value of chromic acid concentration produces a lower thickness value. The voltage is increased up to 6 Volts produce in a decreased thickness value. However, the voltage rises to 7.5 Volts, the thickness increases. It is due to the voltage. It affects the amount of charge reduced from the anode to the cathode. Therefore, the higher the electric voltage applied, the more the number of ions reduced and settles at the cathode.

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It causes the ion layer to stick thicker. It is different from previous research, explaining that the thickness rises when the voltage increases [7].

Table 5 and Fig. 3 describe the highest delta value in the concentration of chromic acid, electricity voltage. Moreover, the lowest in the electroplating time. Therefore, the target value is the average value of each factor's highest S / N ratio. The concentration of chromic acid was 100 mol, the electric voltage was 7.5 volts, and the electroplating time was 10 minutes.

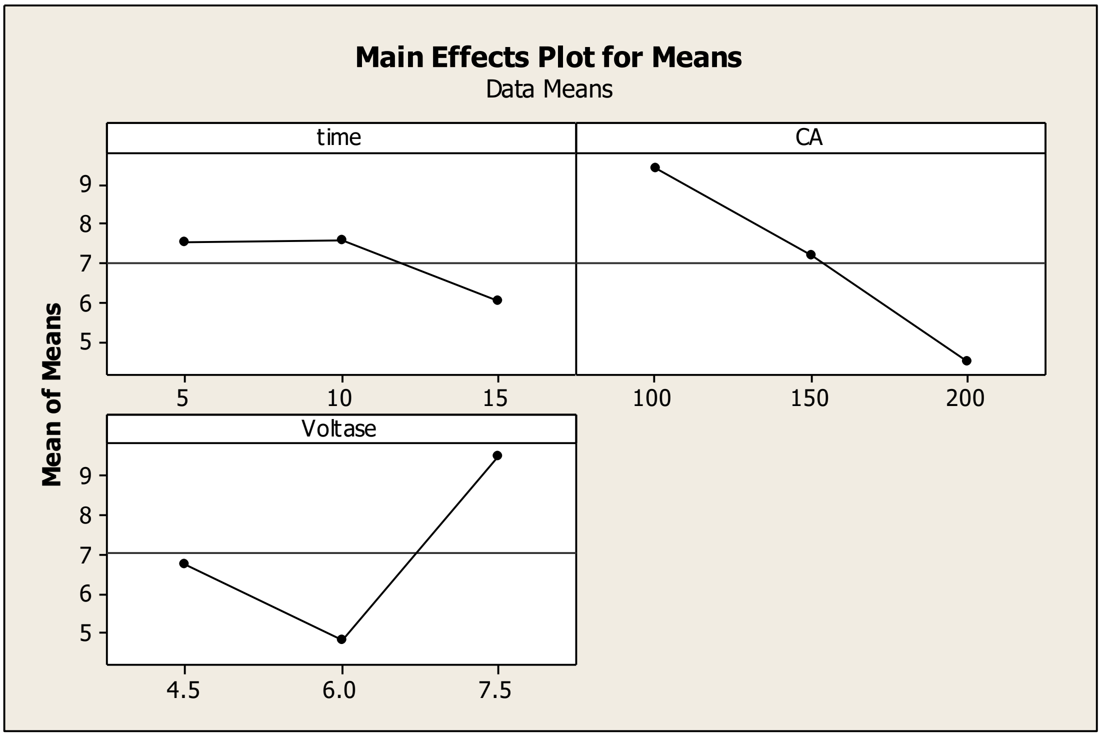

Fig. 3. Graph of S/N for thickness response

4. Conclusion

This research investigates electroplating thickness response analysis on SS304 material using the Taguchi and S/N ratio. The Taguchi method is suitable for determining the optimum of the electroplating process to obtain a proper thickness. Based on ANOVA, the most significant factor for the thickness value in the SS304 electroplating process is the concentration of chromic acid. The second influential electric factors are voltage. The least influence is the time factor of electroplating. For future work, The researcher suggests enhancing factors in the electroplating process, such as the distance between the cathodes. The researchers also suggested enhancing factors significant responses from other implants, such as the corrosion rate of the material.

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