Analysis of Electrochemical Machining on Stainless Steel 304 in Natrium Chloride Solution with Ferric Nitrate Addition

Sri Hastuty[1], Andreas Arnold Rimper[1], Khusnun Widiyati[1], Purwo Kadarno[1], Yudi Rahmawan[1], Muhammad Awwaluddin[2], Poppy Puspitasari[3]

{sri.hastuty@universitaspertamina}

Department of Mechanical Engineering, Universitas Pertamina, Jakarta, Indonesia[1], Research Organization of Energy and Manufacturing, National Research and Innovation Agency, Indonesia[2], Department of Mechanical Engineering, Faculty of Engineering, Universitas Pamulang, Indonesia[3], Mechanical and Industrial Department, Center of Advanced Materials and Renewable Energy Universitas Negeri Malang, Malang, Indonesia[4]

Abstract. The research focuses on static Electrochemical Machining (ECM) applied to 304 stainless steel samples to determine the optimal parameter combination for achieving high material removal rates (MRR) and a consistently smooth surface. Previous studies have extensively explored Electrochemical Machining, while this research approach incorporates ferric nitrate to expedite the ECM process. The study examines various variables, including 25°C, 40°C, and 50°C temperatures, alongside different ferric nitrate concentrations (ranging from 0% to 5%) at 10V, 15V, 20V, and 25V. The ECM procedure is conducted within an acrylic enclosure, utilizing 304 stainless steel as the anode and gold as the cathode, interconnected via a cable to a DC power source. The research identifies an optimal parameter combination: operating at 50°C with 1% ferric nitrate addition and a voltage of 20V. This configuration consistently yields high MRR values while ensuring a uniformly smooth surface on the test specimens.

Keywords: ECM, Temperature, Ferric nitrate, voltage, MRR, Surface roughness

1 Introduction

Stainless steel 304 is a material that is used in the manufacturing world because the manufacturing world requires materials that have corrosion resistance[1]. Therefore, stainless steel 304 is commonly used in the manufacturing world because stainless steel has good corrosion resistance.The manufacturing world requires strong and corrosion-resistant materials to ensure safety and maximize product life [2].

However, the 304 stainless steel material, generally used in the industrial world, requires macro and micro sizes with a high surface complexity. Meanwhile, conventional machinings suchas lathes and milling machines cannot be used tomachining 304 stainless steel with complex surface demands because 304 stainless steel has a relatively high hardness. So, the machining process of stainlesssteel 304 using conventional machining will affect thefinal result, especially on the material's surface characteristics [3].

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Therefore, non-conventional machining, namely electrochemical machining (ECM), was chosen for the304 stainless steel machining process. Electrochemicalmachining can process hard and small objects with a high level of complexity because this machining uses the concept of controlled corrosion so that the electrochemical machining process can produce workpieces with good quality, especially on surface characteristics [4].

There are two types of electrochemical machining: dynamic and static. In dynamic electrochemical machining, a strong electrolytic flow will remove metal particles released from the anode before adhering to thecathode. While static electrochemical machining doesnot use a pump to create a flow of electrolytes, this process uses a stationary electrolyte (static) [5]. Electrochemical Machining (ECM) has drawbacks, namely the various parameters and changes according to the type of material to be processed. Parameters commonly used in ECM are the type of electrolyte, voltage magnitude, current, and temperature in the machining process [6].

2 Material and Method

2.1 Tools and Materials

In this study, stainless steel 304 was used for Electrochemical Machining in NaCl solution with the addition of ferric nitrate at different voltages and Temperatures. The ECM criteria to be achieved are fast grinding, uniform surface grinding results, smooth surface of the test object, and a high MRR value (more than the average calculated value) [7].

2.2 Sample Preparations

In this study, the cutting process of stainless steel 304 with dimensions of 2 x 2 cm^2 in as many as 40 samples. After cutting, stainless steel 304 is sanded using sandpaper with grits of 100, 400, 600, 800, and 1000 CW. The sanding process was carried out using a sanding machine with a speed of 100 rpm. The next stage of preparation is purchasing and manufacturing an electrolyte solution that will be used during the experiment. The prepared electrolyte solution was a NaCl solution with a concentration of 1M and a mixture of ferric nitrate solution with a concentration of 0.2M at 1%, 3%, and 5% of the amount of NaCl solution had been prepared.

2.3 Electrochemical Machining Process

An electrochemical machining test was carried out with voltages of 10, 15, 20, and 25 V at a temperature of 25ºC and a voltage of 10, 15, and 20 V at a temperature of 40 and 50ºC using a prepared electrolyte solution. The temperature setting at the time of the experiment was carried out by placing the electrolyte solution into a glass beaker which was then immersed in a pan heated using an electric stove. The temperature is set using a thermometer. While the amount of voltage used when testing is carried out is regulated from a DC power source.

ECM testing is carried out using a test box made of Acrylic with a hole at the bottom. This ECM test is performed statically, or there is no electrolyte flow during the ECM process. The sample was placed at the bottom of the acrylic box, and an O-ring with a diameter of 1.2 cm made of Teflon was used to limit the part of the sample that was exposed to the electrolyte solution during the ECM process. In addition, the O-ring also functions as a barrier so that the electrolyte solution does not come out of the acrylic box. After that, the nuts and bolts are tightened, and the cable is connected to a DC power source. The positive pole is connected to the workpiece, while the negative pole is connected to the gold cathode. After everything is connected, the heated electrolyte solution is put into an acrylic box, as seen in **Figure 1**. When the temperature of the electrolyte solution matches the parameters used, the DC power source is turned on, and the voltage is adjusted according to the predetermined one. The stopwatch is turned on right after the DC power source is turned on. The test is carried out for 1 minute, and changes in current strength that occur every 5 seconds are recorded. The test is repeated based on the parameters that have been determined.

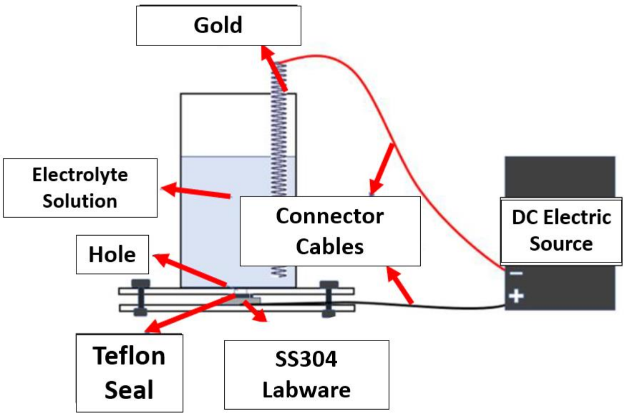

Fig 1. Schematic Diagram of ECM Tools

2.4 Current Density

When the ECM process is carried out, the DC power source screen shows real-time changes in current strength. The visible current value is recorded every 5 seconds once started when the ECM process starts. The current strength value is divided by the surface area of the sample exposed to the electrolyte solution during the ECM process to obtain the current density value. The current density value can be obtained by equation (1).

$$J = I/A \quad (1)$$

J = Current Density (A/m^2)
I = Current (A)
A = Area (m^2)

2.5 Surface Roughness

Sample characterization was carried out using a Zeiss Primo Tech optical microscope connected directly to a computer. This observation was made to see the test results with a magnification of 5, 20, and 50 microns. After the ECM process, a new surface will be formed on the workpiece, so it is necessary to observe the surface roughness to see the surface roughness that occurs on the workpiece. Surface roughness observations are also carried out to determine the surface contour of the workpiece after the ECM process, which can indicate whether the ECM process is successful or not. ECM process is successful if the grinding results are the same or the surface contour is flat [6].

2.6 Material Removal Rate (MRR)

The calculation of the Material Removal Rate value is carried out to indicate the success of the electrochemical machining process, where the higher the MRR value, the better the machining results obtained, with a note that the surface roughness value obtained is also low. The MRR value can be obtained by calculation using equation (2) with description in Table 1.

$$MRR = \frac{m}{t\rho} = \frac{I\ A}{F\rho v} \tag{2}$$

Table 1. Description of MRR Equation

F	Faraday Constant	96500 C/mol
I	Current	Ampere (A)
A	Atomic Weight	9.779825 kg/mol
v	Electron Valence	2
ρ	Density of Material	8000 kg/m3

3. Experimental Result

3.1 Analysis of Current Density

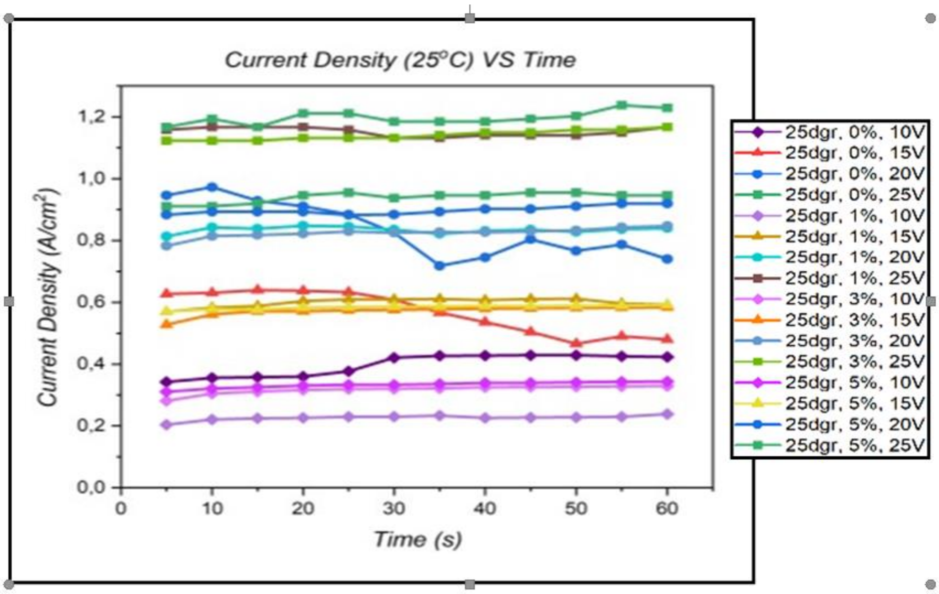

Fig. 2 Current Density (25ºC) VS Time

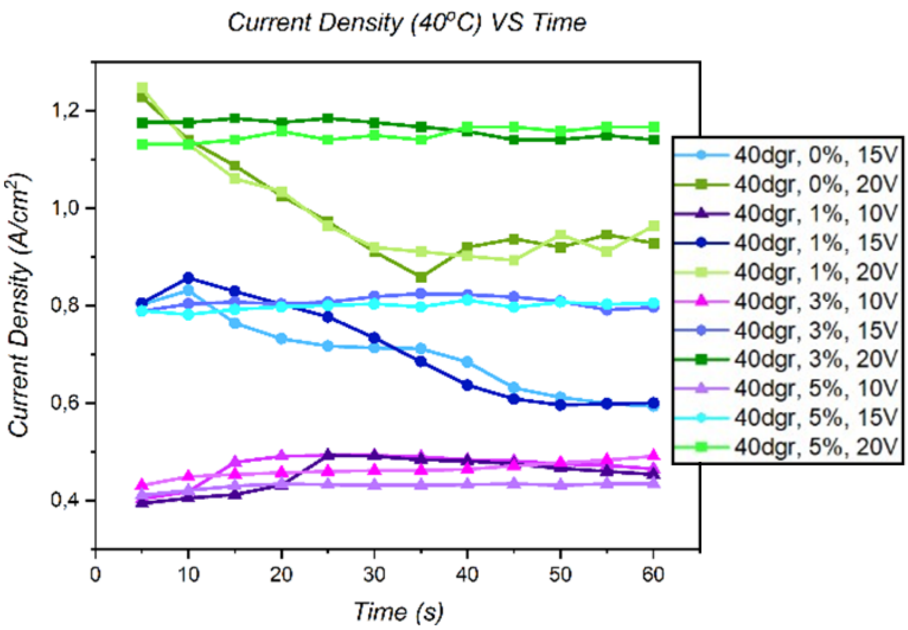

Fig. 3 Current Density (40ºC) VS Time

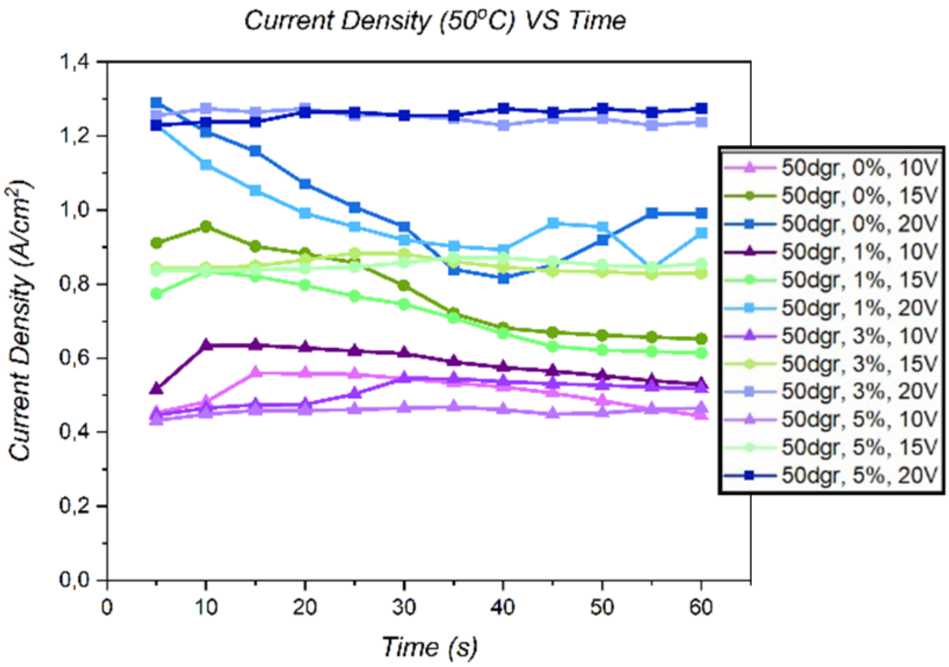

Fig. 4 Current Density (50oC) VS Time

From **Figures 2, 3, and 4** of the relationship between current density and machining time, a combination of voltage parameters influences the current density value and the amount of iron nitrate mixture added. The greater the voltage, the value of the current density will be even greater. The current density value at a voltage of 10 V at each temperature obtained the lowest value range. It may occur because the voltage of 10 V has not been able to erode the passivation layer of 304 stainless steel. The voltage must be more than 12 V for electrochemical machining on 304 stainless steel to erode the passivation layer and chromium layer on 304 stainless steel [8].

However, in the third graph between the current density and machining time, there is an error value at each temperature, where the error occurs uniformly in the parameters of adding 0% and 1% iron nitrate at a voltage of 15 V and 20 V. This happens because the ECM process with a combination of parameters in this case, the material residue remains on the surface of the test object because the electrochemical machining carried out is static electrochemical machining so that there is no flow of electrolyte solution that can clean the surface of the test object from the residue that occurs. In the presence of this residue, the erosion process becomes a barrier and causes the current density value to be lower. This gradual scraping of the test object results in a smoother surface but has a smaller Material Removal Rate (MRR) value. The following is a schematic diagram of the occurrence of a rust layer on the surface of the test object that resists the electrochemical machining process.

3.2 Macro and Micro Observation Results

After calculating the test results data, it is necessary to make macro and micro-observations on the test object. Macro observations were made using a camera, while micro-observations were carried out using a Zeiss Primo Tech optical microscope which was then observed through a computer using ZEN software. **Figures 5 - 8** show Macro Images of 304 Stainless Steel with a ranging voltage of 10V, 15V, and 20V of temperature 50^{o}C various Ferric Nitrate ranging from 0%, 1%, 3%, and 5%, respectively. **Figures 5-8** show that with the increasing percentage of Ferric Nitrate, the corrosion product becomes more significant at the surface area.

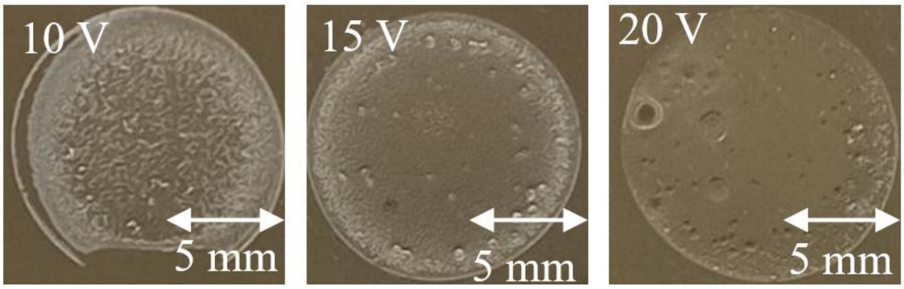

Fig. 5 Macro Image of 50^{o}C without Ferric Nitrate Addition

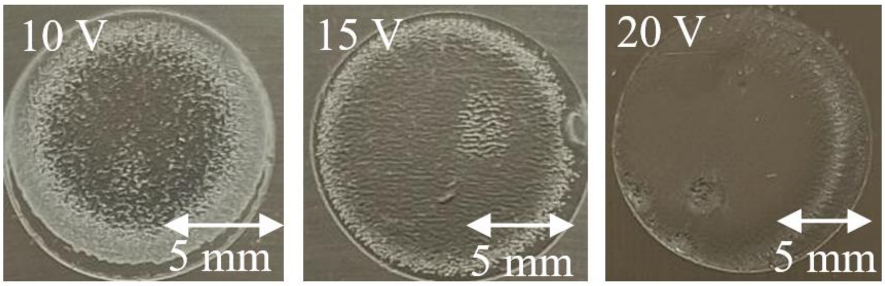

Fig. 6 Macro Image of 50^{o}C with 1% Ferric Nitrate Addition

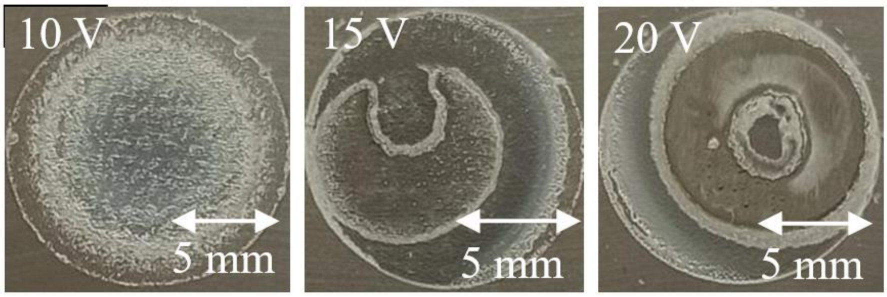

Fig. 7 Macro Image of 50ºC with 3% Ferric Nitrate Addition

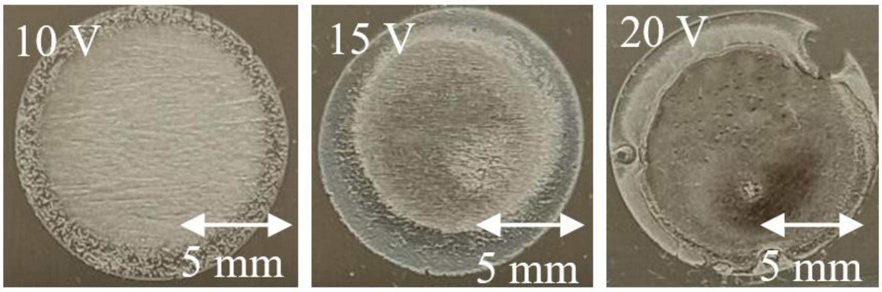

Fig. 8 Macro Image of 50ºC with 5% Ferric Nitrate Addition

This research shows the best macro and micro results with small surface roughness and uniform feeding at parameters 50ºC, 1%, and 20V, as seen in **Figures 9 and 10**.

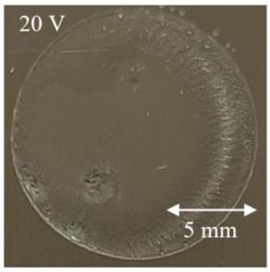

Fig. 9 Macro Image of 50 ºC, 1%, 20 V

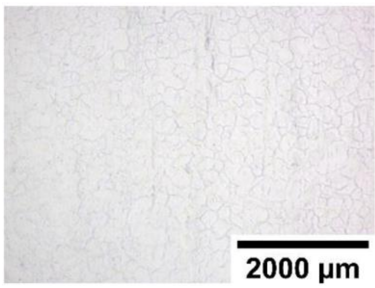

Fig. 10 Micro of 50 ºC, 1%, 20 V at 20x0.4. magnification

3.3 Analysis of Material Removal Rate (MRR)

After knowing the surface of the test object with the lowest surface roughness level or the smoothest specimen and the feeding uniform, the Material Removal Rate (MRR) value is calculated and summarize in **Figure 11**. The success criteria for the ECM process are not only seen from the flat surface contour and uniform feeding but also based on a high MRR value or above the average MRR calculation result [9]. Based on **equation (2)** in Chapter II, the MRR value of each test with various variations of variables can be determined. With different variables ranging from temperature, voltage, and the addition of ferric nitrate, it will certainly affect the current value listed on the DC power source during the ECM process, so the MRR of each experiment will have a different value.

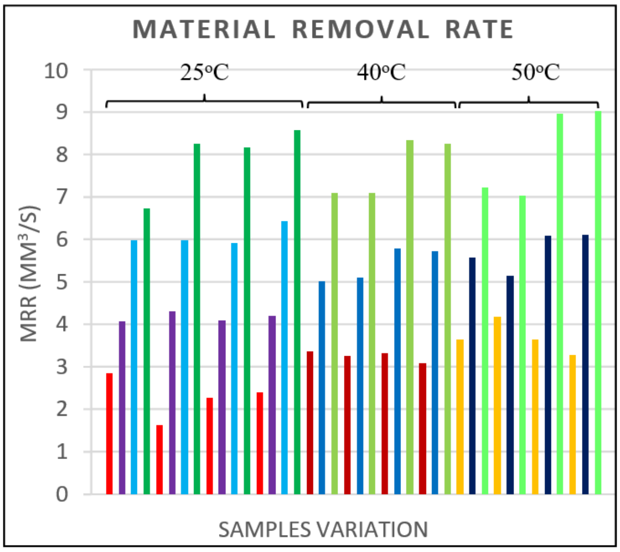

Fig. 11 MRR Value on ECM Test

After the MRR value is obtained from the calculations, it can be seen that the MRR value is directly proportional to the average current value obtained during the ECM process. The higher the average current value obtained, the higher the MRR value that occurs in the specimen [6]. The highest MRR value was obtained by testing with a temperature variation of 50°C and adding 5% ferric nitrate at a voltage of 20 V.

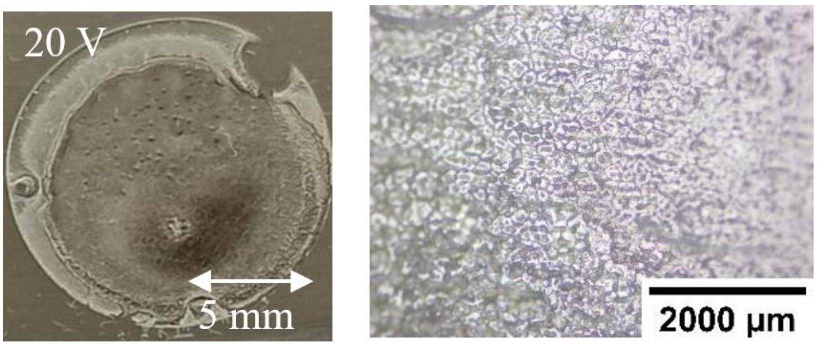

Fig. 12. Macro and Micro Images at 20x0.4 magnification of the Higher MRR Value

After all data analysis methods of current densitycalculations, surface roughness observations, and calculation of Material Removal Rate (MRR) valueshave been carried out, the optimal combination of parameters is obtained at a temperature of 50ºC with the addition of 1% ferric nitrate at a voltage of 20 V.The resulting image and the micro image can be seen in **Figure 12** with the Material Removal Rate (MRR) obtained at 7.02 mm^3/s.

4 Conclusions

The value of current density is directly proportional to the increase in voltage. It can be seenin Fig. 2 - 4. The Material Removal Rate (MRR) value is directly proportional to the current density value, or it can be said that the MRR value is directly proportional to the increase in voltage. The higher the current value created during the ECM process, the higher the MRR value in the ECM process. However, a high MRR value does not always create a test object following the ECM success criteria, where the ECM is said to be successful or produces a suitable test object if the grinding is fast, the grinding results are uniform (uniform/homogeneous), and the surface is smooth.

In this study, the highest MRR value was obtained by testing with a temperature variation of 50ºC and adding 5% ferric nitrate at a voltage of 20 V. It can be seen in **Figure 6** where the ECM process does not occur evenly. The micro-observations obtained the best results at a combination of temperature parameters of 50ºC with the addition of 1% ferric nitrate at a voltage of 20 V. The combination of these parameters has an MRR value of 7.02 mm^3/s.

Thus, based on the research results, the best combination of parameters is a temperature of 50ºC with the addition of 1% ferric nitrate at a voltage of 20 V. The combination of these parameters was chosen because it has an MRR value above the average (5.43 mm^3/s), which is 7.02 mm^3/s, and has a homogeneous surface, so it can be said that the ECM process produces a good test object on the combination of these parameters.

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