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Influence of Material Removal Rate by the Direct Current Power Supply in The Electrochemical Mask Etching Process

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Abstract:

Electrochemical Machining Masking (ECMM) is considered an advanced technique in the field of machining. Various parameters influence both the machining rate and the quality of the machined surface. When utilizing mask electrochemical etching to determine the material removal rate (MRR), several parameters are considered. These parameters include gap, current, concentration, voltage, area, and materials. This study aims to investigate the impact of varying current levels, specifically 5, 10, 15, 20, and 25 Amps, as well as the effect of different machining gaps, namely 2, 4, 6, 8, and 10 centimeters. The investigation involved conducting machining experiments on various materials, namely aluminum, steel, and stainless steel. The dimensions of both the anode and cathode were standardized at 20x20x2 mm. The process of removing material from a substrate can be achieved through either chemical reactions or etching processes. An experiment was conducted on aluminum, steel, and stainless-steel plates. This inquiry pertains to the electrochemical etching process and its impact on material removal rate (MRR), current density, and machining gaps. The findings have been presented. The experimental findings indicate that the material removal rate (MRR) in machining exhibits an upward trend with an increase in current, while conversely, it demonstrates a downward trend with an increase in the gap between the cathode and anode.

Key words*: electrochemical machining masking, current, gap machining, metal removal rate.*

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1. INTRODUCTION

Machining is a manufacturing process that is employed as a secondary measure to eliminate surplus material from a given workpiece. The removal of material is done through shearing, and a cutting tool is used to extract solid chips. This process is used to create the intended object using subtractive manufacturing. There are various machining operations like turning, drilling, and milling. Conventional methods are insufficient for meeting the growing need for downsized products with precise surface integrity and dimensional accuracy. The limitations mentioned above have stimulated the exploration of alternative machining techniques that possess the competence to effectively handle a diverse range of materials and achieve surface finishes at the nanometer scale while simultaneously enhancing accuracy. In response to market demands, a multitude of non-traditional or unconventional machining processes have surfaced, which have proven insufficient in fulfilling the escalating demands for miniaturized products that require exceptional surface integrity and precise dimensional accuracy.(El-Awadi, Enb et al. 2016). Non-traditional machining (NTM) processes are characterized by the absence of shearing phenomena and chip formation. Indeed, these processes do not utilize a traditional cutting tool. Within the realm of non-traditional machining (NTM) processes, a wide array of energy forms are utilized in their original states to facilitate material removal. These energy forms encompass mechanical, thermal, chemical, electrical, electro-chemical, and light energy, among others. Material removal can be accomplished through a multitude of mechanisms, encompassing erosion, fusion and volatilization, and ionic dissolution, among other processes. There are a variety of non-conventional machining techniques (NTM) at one's disposal, such as abrasive jet machining, ultrasonic machining, electro-chemical machining, electro-discharge machining, and laser beam machining, to name a few. Each particular technique boasts unique capabilities and is exceptionally adept for designated purposes.(Debnath, Kunar et al. 2017, Younas, Manzoor et al. 2017, Kalita, Chakraborty et al. 2023).

Electrochemical machining (ECM) is a notable technique that distinguishes itself among various machining processes. The aforementioned procedure can be elucidated as the antithesis of electroplating, albeit with specific alterations. The fundamental principle underlying this phenomenon is deeply rooted in the intricate process of electrolysis. The mobility of unbound electrons facilitates the conduction of electricity in metallic substances. On the contrary, within solutions, the conduction of electrical current and the movement of electric current in an electrolyte are made possible by the migration of ions. As a result, the transportation of substances occurs at the same time as the flow of electric current. In electrochemical machining (ECM), the work piece is firmly fastened to a positively charged electrode, while the tool is connected to the negatively charged terminal. This arrangement allows for the removal of metallic elements.(G.A.El-Awadi 2023). Based on the research conducted by, electrochemical micro machining has been recognized as a significantly advantageous technique, demonstrating considerable potential as a prospective approach for micro-machining. In a study conducted by (Bhattacharyya and Sorkhel 1999). This investigates the influence of a variety of factors, including the molar concentration, duration of electrolysis, applied voltage, and distance between electrodes, which can be considered multiple variables, on the quantification of material removal rate (MRR) and the diameter of perforations generated. The findings indicate a direct correlation between the metal removal rate (MRR) and the progressive molar concentration of the electrolyte and electric voltage. This study examines several parameters, including the flow rates of the electrolyte, the rate of feeding, the voltage, and the chemical composition of the electrolyte. The study employed two distinct electrolyte solutions, namely sodium nitrate (NaNO3) and sodium chloride (NaCl).(Kunar, Mahata et al. 2018).

The results suggest that the feed rate exerted the most significant influence on the material removal rate (MRR)(Rai and Kumar). Several investigations were carried out with the aim of scrutinizing the impact of process parameters on the rate of material removal (MRR). The process parameters, namely the machining voltage and inter-electrode gap (IEG), were adeptly regulated through the utilization of an exclusive setup that was made accessible for the purpose of experimentation. The experimental investigation encompassed the examination of the machining voltage and IEG as independent variables in order to analyze their respective effects on the material removal rate (MRR). As the independent variable of interest, denoted as IEG, experiences a gradual decline, a corresponding upward trend is observed in the dependent variable, known as MRR. The voltage variable is consistently maintained at a constant level throughout the entire duration of the experimentation. The implementation of the inter-electrode gap (IEG) with a thickness of 0.20mm results in a notable augmentation in the parameter of interest in this context, the material removal rate (MRR). Furthermore, it is imperative to consider the disparity between the conceptual Material Removal Rate (MRR) and the actual MRR in order to mitigate the percentage error. (Uttarwar and Chopde 2013, Gobinath, Hariharan et al. 2022).

The researchers are currently engaged in an inquiry regarding the impact of process parameters on the material rate of removal (MRR) and surface roughness (SR). The process parameters, including machining voltages, feed rate, current, electrolyte concentration, and electrolyte flow, were effectively managed and adjusted as required. The study involved a thorough examination of various combinations of manipulated variables to ascertain their influence on the material rate of removal (MRR) and roughness of the surface (SR) of the workpiece.(Tailor, Agrawal et al. 2013, Kadam and Mitra 2021). Electrochemical machining (ECM) is a process used for the removal of metal that functions by means of anodic dissolution. This particular technique has been specifically developed for workpieces that exhibit electrical conductivity. Electrochemical machining (ECM) involves the utilization of a formed electrode tool to achieve the desired shape of the workpiece(Kozak and Zybura-Skrabalak 2016, Asmael and Memarzadeh 2023). The positioning of the electrode tool very near the workpiece is essential for facilitating the intended machining process. It is crucial to recognize that the electrode tools and the workpiece are efficiently separated by a swiftly flowing electrolyte. The electrochemical machining process (ECM) can be understood as a method of selectively removing material through a controlled electrochemical dissolution process. The workpiece serves as the anode, while the tool functions as the cathode. The basic idea behind this process is that material is selectively taken from the anode (the positively charged electrode) and then put on the other side of the anode (the negatively charged electrode).

The determination of metal removal rate is governed by Faraday's First Law, which posits that the extent of chemical conversion induced by an electric current, especially the dissolution of metal, is directly correlated to the quantity of electric charge transferred, as denoted by the product of current and time.(Tsai, Lin et al. 2021). The initiation of ion movement between the tool and the workpiece occurs when an electrical potential difference is applied across the electrode. The cathode, serving as the instrument, exhibits an attractive force towards ions with positive charges, whereas the workpiece exhibits an attractive force towards ions with negative charges, as illustrated in Figure 1. This illustration will examine the machining process of low-carbon steel, which is predominantly a ferrous alloy composed mainly of iron. In the realm of electrochemical machining applied to steel, it is customary to utilize a neutral electrolyte solution comprising sodium chloride (NaCl). Ionic dissociation is a phenomenon that takes place within the electrolyte and water when a potential difference is introduced, as outlined below.

The primary aim of this study is to investigate how the rate of material removal in electrochemical machining etching is affected by two key variables: current density and the distance between the anode and cathode. The research will specifically focus on three distinct substrate materials: aluminum, steel, and stainless steel.

2. EXPERIMENTAL WORK

Electrochemical machining mask etching was used to investigate how direct current and gap distance affect metal removal (MRR). These include voltage, current, and power density. Researchers and practitioners can improve etching quality, uniformity, and selectivity by manipulating and improving these factors. Thus, understanding how current density and gap distance are affected, the metal removal rate MRR can calculated as the following formula:

$$MRR\ in\ wt = \frac{(intial\ weightWi - Final\ weight\ Wf)}{density\ of\ workiece\ (\rho w)xtime} = gm/sec$$

$$MRR = \frac{(Wi-Wf)}{\rho w.\ time} = gm/sec \tag{1}$$

Where wt = Metal removal rate per weigh/gm, W_i = initial weight, W_f = final weight, ρ_w= density of work piece.

$$\text{MRR} = \frac{GI}{\rho F} \tag{2}$$

G =gap distance I= current F= faraday number and ρ =density

The methodology used to design and manufacture ECM mask etching is based on the basic engineering concepts, fundamentals, and technical calculations in the field of mechanical design with traditional design methods. This methodology is briefly outlined through the following steps:

2.1. Materials and Sample Preparation

The inquiry utilizes three distinct sorts of material, namely aluminum, steel, and stainless steel. These materials are extensively employed in diverse industrial applications, with a special emphasis on electrochemical operations, including stamping, decorating, blanking, micromachining, polishing, and the formation of complex shape profiles.

This study employed three distinct materials, namely aluminum, steel, and stainless steel, to investigate the impact of MR under varying parameters. Table 1 displays the pertinent information regarding the material properties and chemical composition of aluminum (Al), low-carbon steel, and stainless steel 304. The specifics pertaining to the previous work (G.A.El-Awadi 2023).

Table 1. The material's properties and chemical composition

Type of Material	Electric conductivity ($10*10^6$ Siemens/m)	Electric resistivity ($10*10^8$ Ohm.m)	Density (g/cm^3)	Components Elements (%)
Aluminum (3A36)	36.9	2.7	2.7	Al (95.25), Si (0.6), Fe (0.7) Mg (0.5), Cu (0.5), Mn (1.6) Cr (0.1)
Steel (A36)	10.1	9.9	7.8	C (0.29), Cu (0.2), Fe (98) Mn (1.03), Si (0.28)
Stainless steel (304)	1.37	73.0	7.9	C (0.08), Mn (0.2), Si (0.75) Cr (20), Ni (8), Fe (71)

2.2. Basic setup for electro-etching by DC power supply

2.2.1. Electrolytes

The electrolytes employed in the process of electro-etching When the current density is too high, striations and a coarse etching effect are frequently present, along with the fast action of sodium chloride. Efficient electro-etching can be achieved with a varied range of electrolyte concentrations. Electrolyte concentrations can vary to attain efficient electro-etching. The low-concentration solutions can extend the process, resulting in a gradual deterioration of the resist. On the other hand, solutions with excessive concentration can impede the etching process and compromise the quality of the output, making them impractical for chemical utilization. Nevertheless, variations in concentration can occasionally lead to disparities in the quality of the etching process.

The concentration of electrolyte solutions is expressed using the term molality, denoted as M. A 1 mole solution is comprised of the solute's molecular weight, expressed in grams, that has been dissolved in 1 liter of distilled water. The molar mass of sodium chloride (NaCl) is 58 grams per mole. There are several notable advantages associated with the utilization of a sodium chloride solution for the process of electro-etching. Firstly, it is a cost-effective option, as sodium chloride (NaCl) is readily available and relatively inexpensive.

Additionally, the preparation of this solution is straightforward and does not require complex procedures. Furthermore, the etching capability of sodium chloride solution is highly pronounced, displaying a notably aggressive nature in its etching properties. One of the drawbacks associated with etching is the presence of metal salts in the electrolyte solution post-process. It is important to note that a more thorough approach is necessary for the disposal of metal salts rather than simply disposing of residual solutions in a drain. When sodium chloride is used for electro-etching, hydrogen bubbles will quickly come out of a clean cathode soon after the process starts. In the event that the cathode becomes contaminated, the resulting effects may not be readily discernible. The formation of bubbles on the anode indicates a reversal in the polarity of the circuit, necessitating the interchange of the leads connected to the anode and cathode.

2.2.2. DC power supply

To control DC power, the XLN6024 Variable Linear Single-Output DC Power Supply was used, 0-30V at 0-24 Am. This particular power supply provides superior management over both voltage and current, granting the opportunity for highly regulated repetition of multiple reproductions of an etched item.

2.2.3. Etching tank

Samples prepared for the electrochemical etching process with dimensions of 20x40x20 cm and fixed the spacer to determine the gaps between the anode and cathode at 2,4,6,8 cm,

2.2.4. Water pump

DC water pump to circulation path and remove removal practical from electrolyte during machining Model ROHS: Input: Dc 12 v, head: 4-6M, Q max: 600-800l/H.

2.3. Sample preparation and masking

Samples were polished using different techniques, including polishing papers and cleaning. In order to remove any oils or grease, denatured alcohol or acetone is applied through wiping, as shown in figure 1. We advise against utilizing rubbing alcohol and fingernail polish remover as alternatives for denatured alcohol and acetone due to the presence of oils and other ingredients that may linger on the metal surface. The samples were covered by masking polymer sticks with substrate. This involves placing and sticking the mask onto the desired surface. The mask protects the underlying material. Unwanted portions are carefully removed using precise tools. To start the process, it is recommended to use Scotch tape that covers the designated area. The tape is positioned carefully on the surface. The mask's design is intricately incorporated while the tape is firmly applied to the vinyl surface. Multiple tape strips can hide the design. Align strips to slightly overlap. Remove the backing paper from the vinyl material to reveal the adhesive surface. Hold the sticky side down. Place the design on metal and press it. Vinyl touches metal.

Make vinyl smooth and shiny on metal. Carefully remove the tape, ensuring the design stays on the metal. Tape does not remove substance. Remove the tape strips in reverse order, as shown in figures 2 and 3. Polish vinyl for good adhesion to metal; objects come off with tape. The anode sheet is placed on the cathodic face of the metal blank in relief etching. In order to initiate the procedure, it is necessary to acquire a piece of contact paper that is marginally larger than the metal blank in terms of dimensions and extends an inch beyond the height of the metal blank. It is further essential to create a small horizontal aperture on the contact paper, proximate to the upper region where the metal blank is to be situated. As demonstrated in Figure 4, the aperture must have a width that is sufficient to accommodate the aluminum, steel, and stainless-steel strips while also being narrower than the metal blank.

The samples are prepared for the etching process. It is imperative to ensure that the electrolyte does not come into contact with any of the presented sample strips while they are immersed in the reservoir.

The setup is easily accomplished by providing a direct-current power source with adjustable voltage and current. The current and voltage can be adjusted to meet the specific requirements of the work piece while considering its dimensions. Additionally, the setup requires the presence of salt (NaCl) and water. This particular experimental procedure finds diverse applications in the industrial sector, such as blanking, polishing, and complex shapes. Moreover, it enables the machining of highly compacted shapes on various materials that may not be feasible through alternative methods that do not involve the application of heat. Notably, the success of this method depends on the conductivity properties of the materials being processed, particularly their hardness or ductility.

Figure 1. Polishing samples.

Figure 2. Samples covered by mask.

Figure 3. Cutting machining area etched.

The solution of electrolyte should be prepared and subsequently placed within the etching tank. To establish an electrical connection, it is necessary to affix the positive (+) terminal of the power source to one extremity of a red wire. Subsequently, the opposing extremity of the red wire should be connected to the anode, which refers to the metallic component intended for the etching process. In order to establish an electrical connection, it is advised to affix the terminal of a black wire to the negative (-) terminal of the power supply. Subsequently, the opposite terminal of the aforementioned black wire should be connected to the cathode, as visually depicted in Figure 4.

It is important to note that any exposed metal that comes into contact with an electrolytic solution on the anode part of the etching reservoir will undergo the etching process. The wire, commonly referred to as the alligator clip, is employed to affix the metal blank intended for etching to the positive lead originating from the power source. The electrolyte lacks the ability to distinguish between materials suitable for etching and those unsuitable for etching. It is advisable to apply a protective coating, such as a resist, to any metallic components connected to the anode that could potentially interact with the electrolyte(Sen and Shan 2005).

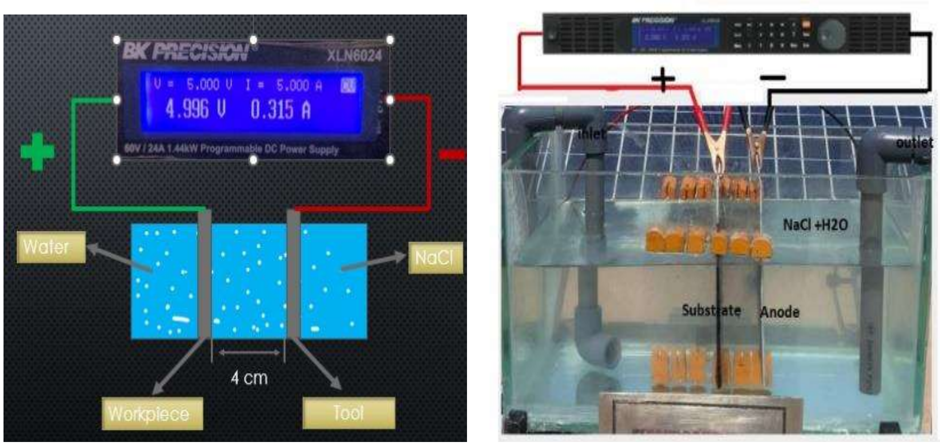


Figure 4. Set up of electrochemical etching.

2.4. DC etching station:

Power Supply:	DC - Linear DC Power Supply with Variable Output Voltage and Current, 0-30V and 0-24Amp.
Tanks:	Acrylic Food Storage Canisters
Electrolyte:	NaCl 0.5, Mole concentration
Digital Timer:	for timing the etching process
Water pumping flow:	The flow cycling process encompasses a delicate movement that filters the electrolyte with precision while it is being returned to its designated storage container.

3. RESULT AND DISCUSSION

The result shown below it's for the effect of current, gap distance, and time on the MMR on three material aluminum and steel and stainless steel.

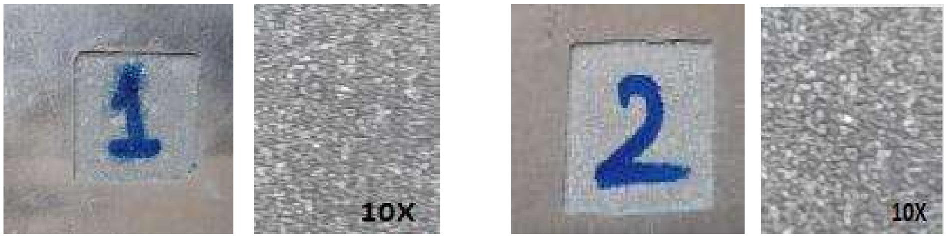
3.1. Effect of current on MRR for machining Aluminum, steel and stainless-steel sheet

This experiment aimed to investigate the impact of electric current on the electrochemical operational process. Specifically, we examined how the potential difference the interaction between the cathode and anode is of significant importance. the speed of ionization and the rate at which materials are removed. Additionally, we explored the effects of varying current intensities (5, 10, 15, 20, and 25 Ampere) on aluminum, steel, and stainless steel. Throughout the experiment, we maintained constant factors volt is 5, electrolyte concentration 0.5 mole and gap machining 4 cm.

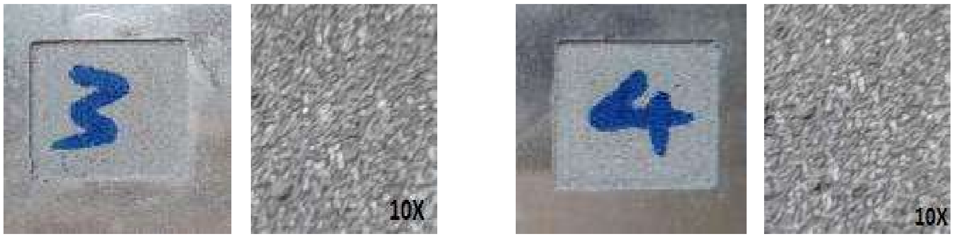
3.1.1. Results of MRR vs current for aluminum

This experimental study aims to investigate the influence of electric current on the material removal rate (MRR) for aluminum metal. the observed reading values for a given set value of v = 5 and I = 5. The passage illustrates the consistent measurement of voltage throughout the experiment while noting that the power increases as the resistance decreases, which can be attributed to the rising resistivity of the electrolyte.

The experimental results presented in Figure 5 demonstrate the impact of varying current (ranging from 5A to 25A) on the material removal rate (MRR) and surface finishing of aluminum during machining(Polat, Makaraci et al. 2010, Basha, Basha et al. 2022). The study specifically examines the influence of changing current on MRR, while keeping other factors constant, such as voltage, electrolyte concentration, and type of electrolyte. There is a direct relationship between the increase in current and the increase in MRR. The samples post-machining, as depicted in Figure 6.



a) Current 5Amp. b) Current 10 Amp.



c) Current 15Amp. d) Current 20 Amp.

Figure 5. Al machining samples at I = 5, 10, 15, 20 Amp.

Electrochemical machining involves the conversion of conventional electrical current within the electrode into ionic current at the interface of the electrode and electrolyte. Based on the principle of charge conservation, it is imperative that the currents in question exhibit equilibrium at this juncture. The transition between the two forms of electrical current can occur as a result of electrochemical reactions, specifically electrolysis, or through the process of capacitive charging. Electrolysis is a phenomenon that takes place when a chemical species present in the electrolyte solution undergoes a process of electron exchange with the electrode. Capacitive charging is a phenomenon that arises when there is a variation in the potential of an electrode. This variation causes ions present in the electrolyte to be either attracted to or repelled from the surface of the electrode, thereby resulting in the flow of an electric current. (Kulkarni 2006, Leese and Ivanov 2016).

Within the domain of electrical phenomena, it is widely recognized that the presence of closed pathways, commonly known as circuits, is a fundamental requirement for the flow of electric current. The presence of a single electrode-electrolyte interface does not possess the ability to produce a net current. However, a system consisting of two such interfaces have the potential to generate a net current. An electrochemical cell is a type of electrochemical system that consists of two or more electrodes that are in direct contact with an electrolyte.(Singh Patel, Agrawal et al. 2020)

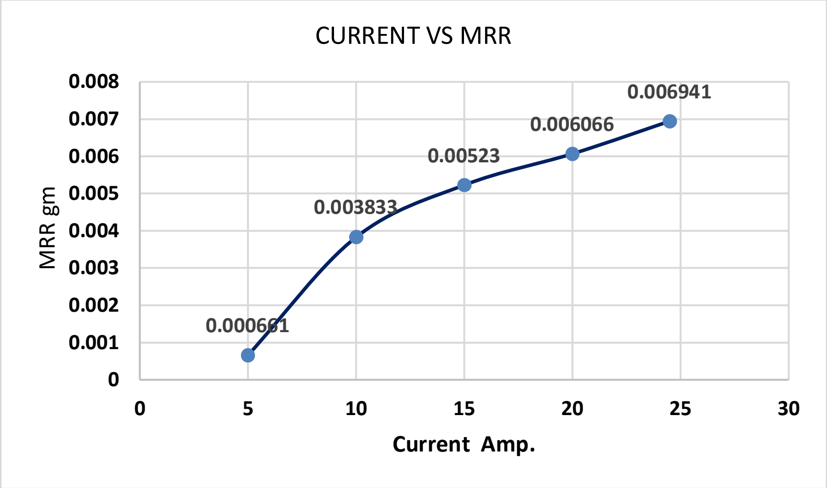


Figure 6. The effect of changing the current on the MMR when using aluminum

3.1.2. Experiment results of MRR vs. current for steel

The primary objective of this experimental study is to examine the impact of electric current on the material removal rate (MRR) in the context of steel metal. The data depicted showcases the observed reading values corresponding to the specified set value of v = 5 and I = 5. The passage examines the consistent measurement of voltage during the experiment, highlighting the relationship between power and resistance. It suggests that the increase in power is a result of the decreasing resistance, which can be attributed to the rising resistivity of the electrolyte

The impact of varying current levels, ranging from 5 to 25 A, on the Material Removal Rate (MRR) during the machining of steel materials is depicted in Figure 7. This analysis was conducted while keeping all other factors constant. The metal removal rate (MRR) exhibits a direct correlation with the augmentation of current.

3.1.3. Experiment results of MRR vs current for Stainless steel.

The experimental results illustrate the influence of different current levels (ranging from 5 to 25 A) on the material removal rate (MRR) in the machining process of stainless-steel materials, as depicted in Figure 8. The surface finishing of a substrate is influenced by various factors, including the application of current and voltage, the type of electrolyte used, and its concentration(Basha, Basha et al.

2022). These factors affect the surface roughness of the machined substrate. The surface roughness is negative correlated with the current. Figure 9 depicts the correlation between current and the material removal rate (MRR) and displays the observed outcomes. There is a positive correlation between current and material removal rate (MRR).

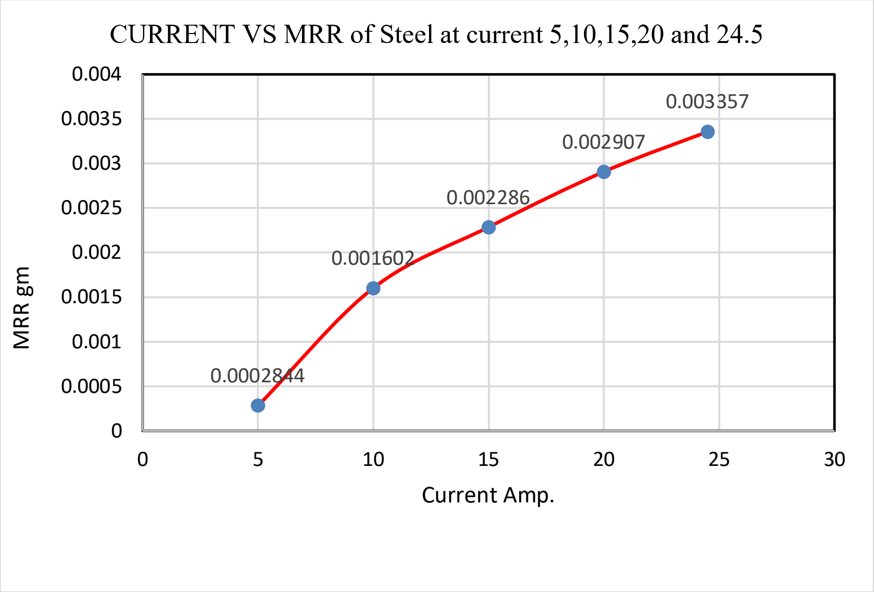


Figure 7. The effect of changing the current on the MMR when using steel

Figure 8. St.steel at different current 5, 10, 15, 20 and 25 Amp.

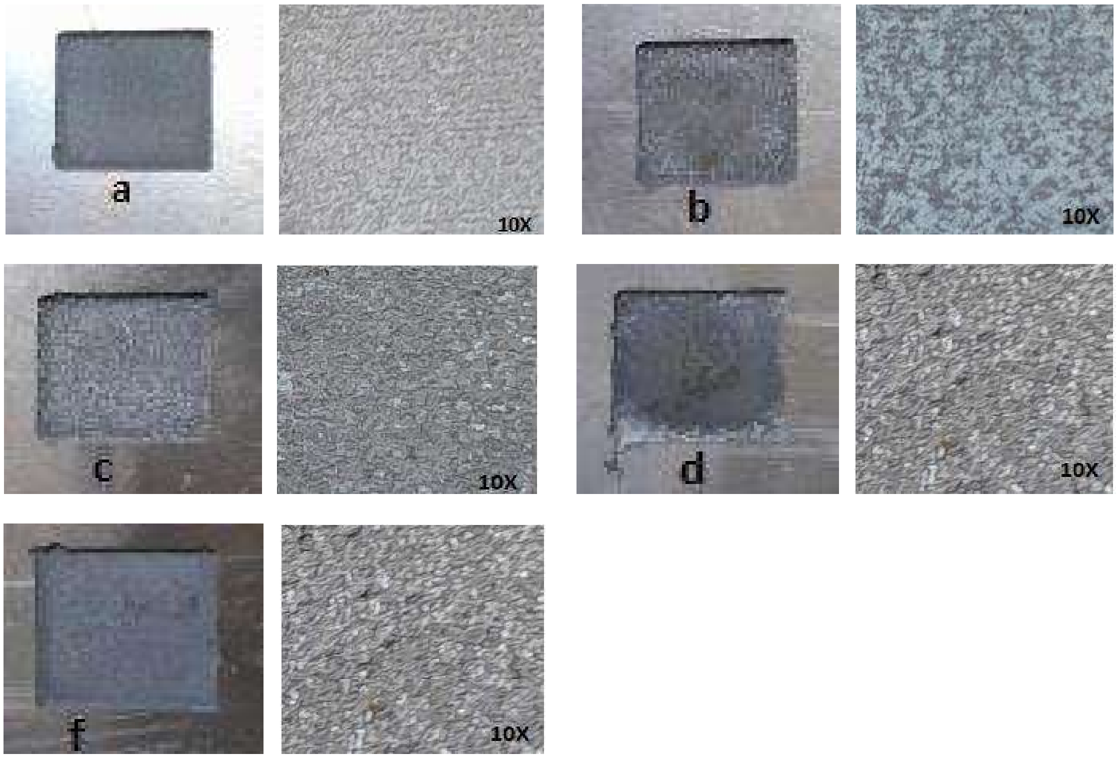


Figure 9. St.steel at different current a) 5, b) 10, c) 15, d) 20 and f) 25Amp.

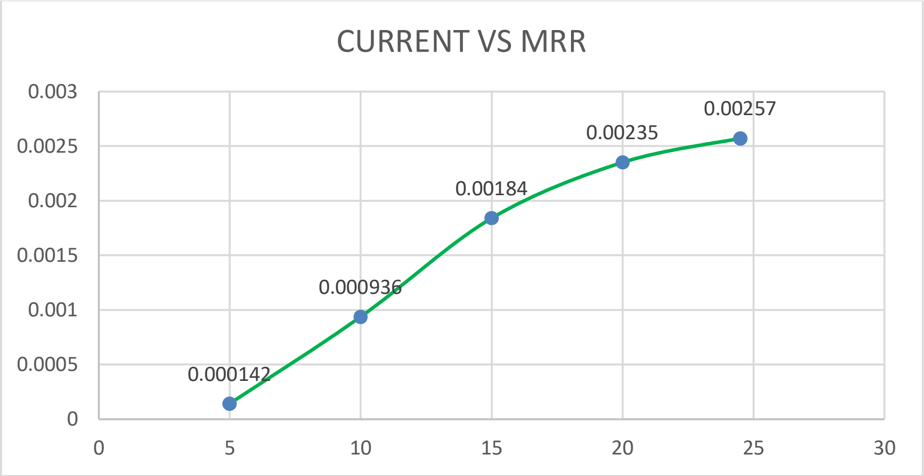


Figure 10. The effect of changing the Current on the MMR when using Stainless steel

3.1.4. Comparison between three types of Materials machining at the same condition

The findings indicate that the material type significantly influences the Material Removal Rate (MRR) in machining operations, with the highest MRR observed for aluminum, mild steel, and stainless steel, respectively. The mean reciprocal rank (MRR) demonstrates a positive correlation with the increase in current, as depicted in Figure 11.

The provided graphs illustrate the relationship between current and material removal rate (MRR) for aluminum, steel, and stainless steel. The data was obtained by maintaining a constant 0.5mol concentration and a 4cm distance, while varying the voltage from 5V to 30V. It is evident from the graphs that as the current increases, the MRR also increases. Notably, aluminum exhibits the highest MRR among the three materials, owing to its specific properties such as density, conductivity, and resistance. Following aluminum, steel and stainless steel demonstrate a comparatively lower MRR.(Debnath, Kunar et al. 2017)

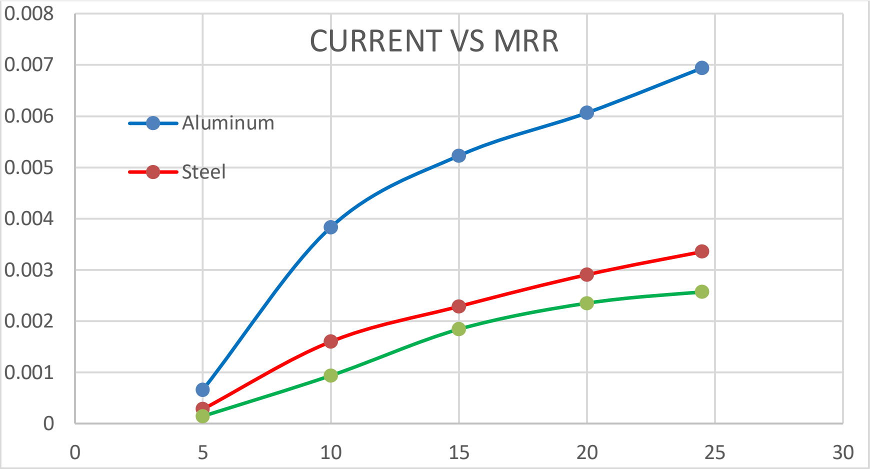


Figure 11. Comparison between three types of material machining at the same condition Comparison of different materials at different currents, electrolyte concentration of 0.5 mole, gap of 4cm, and voltage of 5

3.2. Effect of gap distance

The purpose of this experimental inquiry is to analyze the effect of the spatial separation between the anode and cathode on the electrochemical process. The principal goal of this investigation is to assess the impact of the voltage disparity between the cathode and anode on both the rate of ionization and the speed at which substance is eliminated. The main objective of this study is to examine and evaluate the consequences arising from the manipulation of distance intervals, specifically at increments of 2, 4, 6, 8, and 10 centimeters, on three distinct materials: aluminum, steel, and stainless steel. It is important to know that the experiment will have constant variables, such as a constant potential difference of 10 volts, a constant concentration of NaCl at 0.5 mol, and a stable current intensity of 10 Am.

3.2.1. Effect of different machining gaps on MRR vs. inter-electrode for aluminum

This experimental study aimed to investigate the impact of distance on the material removal rate (MRR) for aluminum (Al) metal. The primary objective of this experimental investigation is to examine the impact of the gap distance on the material removal rate (MRR) in relation to aluminum (Al). The recorded reading values corresponding to the given set values of v = 10 and I = 5. This section examines the uniform measurement of voltage throughout the experiment while acknowledging the direct relationship between power and resistance, whereby power increases as resistance decreases. The observed phenomena can be attributed to the escalating resistivity within the electrolyte.

3.2.2. Effect of gap thickness on the real current of two electrodes

The experiment investigates the relationship between gap distance and current values, as depicted in Figure 12. The findings indicate that increasing the gap distance leads to a decrease in the actual current. This suggests that as the gap distance increases, the resistance also increases, resulting in a decrease in current flow. This relationship also extends to a decrease in power and a reduction in the rate of metal removal as the gap distance increases. The subsequent results will provide further insight into these observations.

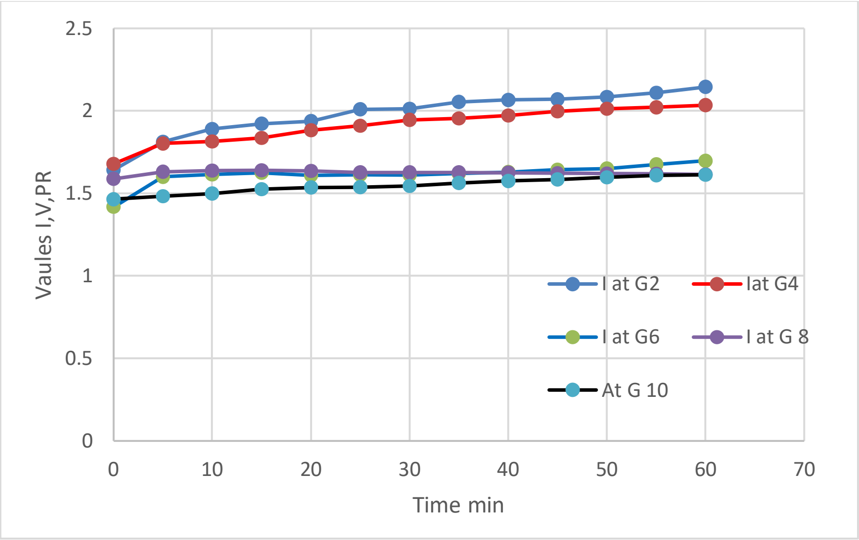


Figure 12. Effect of gap thickness on the real current of two electrodes

The experimental findings demonstrate that the manipulation of distance, ranging from 2 to 10 cm, has a discernible impact on the Material Removal Rate (MRR) during the machining process of aluminum materials. This effect remains consistent even when other factors are held constant, as depicted in Figure 13. The metal removal rate (MRR) exhibits a negative correlation with distance, whereby an increase in distance leads to a decrease in MRR.

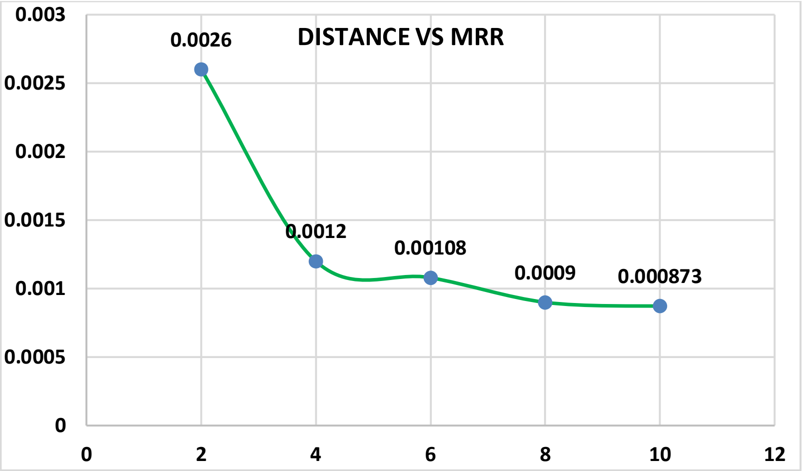


Figure 13. The effect of changing the gap distance on the MRR when using aluminum.

3.2.3. Experiment results of MRR vs Inter-electrode gap for Steel.

This experimental study investigates the impact of varying distances on Material Removal Rate (MRR) for Steel metal. The data pertaining to reading, as illustrated in figure 15. The impact of varying the distance from 2 to 10 cm on the Material Removal Rate (MRR) during the machining of steel materials is demonstrated in Figure 14. This effect is observed while keeping all other factors constant. There is a direct correlation between the increase in distance and the decrease in MRR.

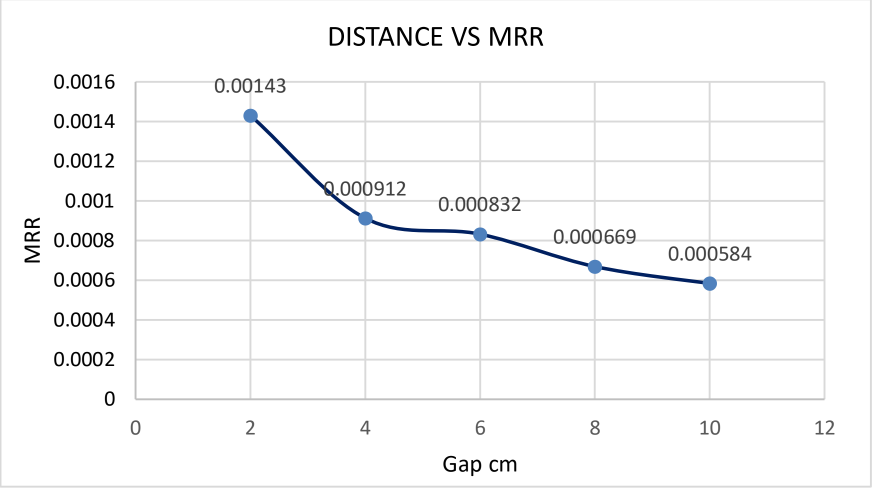


Figure 14. The effect of changing the gap thickness on the MRR when using steel.

3.2.4. Experiment results of MRR vs Inter-electrode gap for Stainless steel

The primary objective of this experimental investigation is to analyze the impact of varying distances on the material removal rate (MRR) within the domain of stainless steel. The data obtained from the reading is illustrated in Figure 15. Figure 16 illustrates the influence of altering the distance within the range of 2 to 10 cm on the Material Removal Rate (MRR) in the process of machining stainless steel materials. It is important to note that all other variables remain unchanged throughout the experimentation. The metal removal rate (MRR) demonstrates an inverse relationship with distance, wherein an augmentation in distance leads to a reduction in MRR. This study aims to compare the performance of various materials under different inter-electrode gap conditions. The experimental setup involved a series of concentrations, specifically 0.5 moles, of 2, 4, 6, 8, and 10. The current was maintained at a constant value of 10, while the voltage was set at 10. The machining process lasted for 60 minutes.

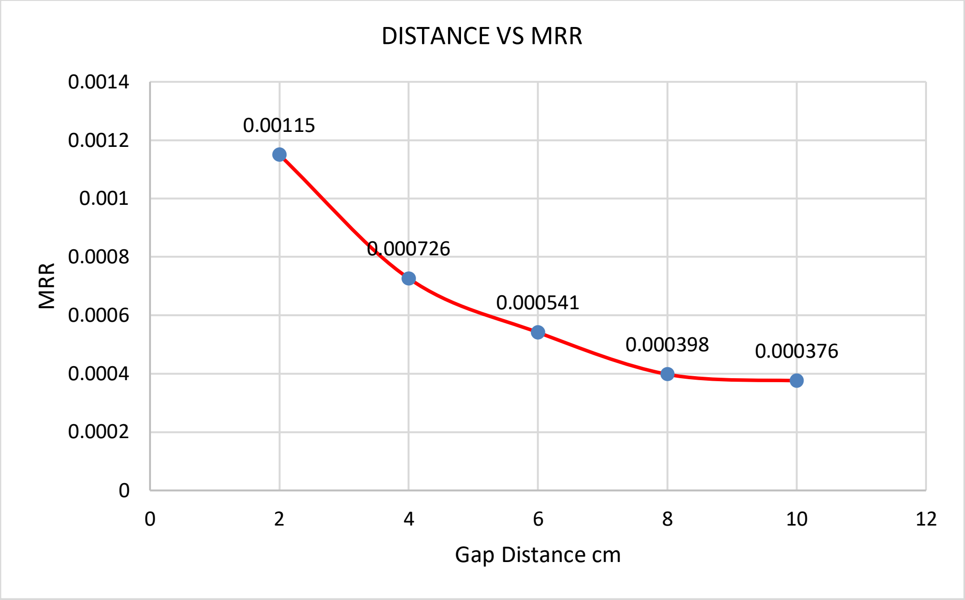


Figure 15. The effect of changing the electrode gap on the MRR when using Stainless steel.

3.2.5. Comparison between three types of Materials machining at the same condition.

The objective of this research study is to conduct a comparative analysis of the efficacy of various substances across diverse inter-electrode gap scenarios. The experimental setup involved a specific electrolyte concentration of 0.5 moles, with a varying distance between the electrodes ranging from 2 to 10 cm, increasing by increments of 2 cm. A constant current of 10 units was applied, while the voltage was set to 10 units. The machining process was carried out for a duration of 60 minutes.(Snoeys, Staelens et al. 1986).(Zhao, Huang et al. 2022).

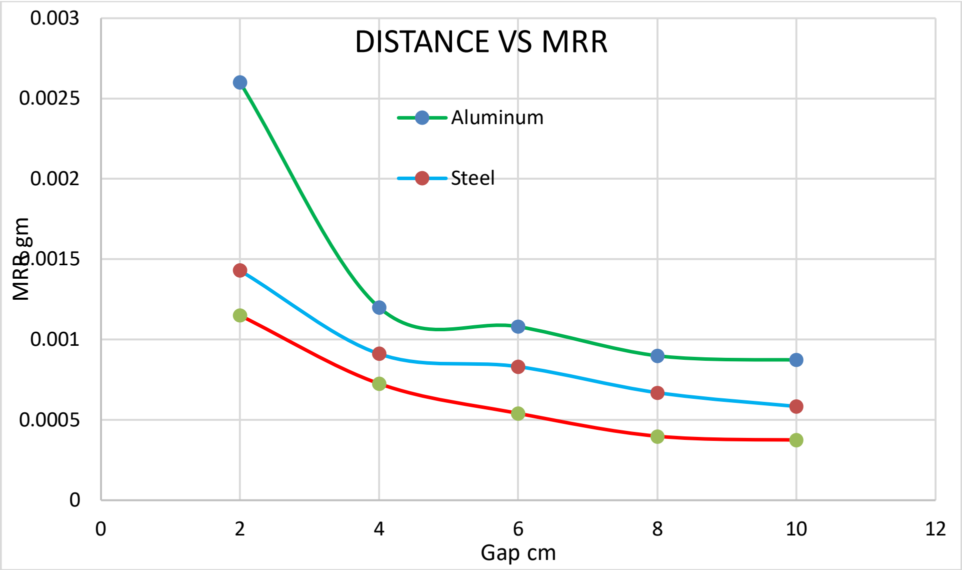


Figure 16. Comparison of different materials at different Inter-electrode gap.2, 4, 6, 8 ,10 concentration 0.5 mole, current 10 Amp and voltage 10 V, time machining 60 min.

The rate of material removal diminishes as a spatial extension is observed between the cathode and anode, as evidenced by the graphical representation (Figure 16). This phenomenon can be attributed to the heightened resistance resulting from the increased gap, which subsequently causes a decline in the current. Consequently, this reduction in current prompts a decrease in the rate at which material is removed. As illustrated in the aforementioned diagram, it is evident that aluminum exhibits the most notable material removal rate owing to its diminished resistance when compared to steel and stainless steel.

4. CONCLUSION

Electrochemical machining (ECM) is a highly efficient technique for shaping thin sheets, producing cavities, performing blanking operations, and drilling holes. However, accurate outcomes necessitate the implementation of a precise mechanism. To ensure efficient current flow in the solution, it is necessary to maintain consistent stirring or pumping and regularly clean to remove metal chloride and metal hydroxide. These substances have been identified as impediments to the flow of electrical current within the solution. There is a direct relationship between the metal removal rate (MRR) and the current magnitude in the anode-cathode circuit. The metal removal rate (MRR) decreases with an increase in the spacing between the anode and cathode. The machining process affects the material removal rate (MRR), which is dependent on the atomic weight of the materials utilized. Aluminum (Al) has a higher material removal rate (MRR) than steel and stainless steel. The surface machining process is influenced by both the current and the gap thickness. The metal removal rate is directly proportional to both the machining time and the area of the machining parts.

Nomenclature

Nomenclature	
V	Volt
I	Current
R	Resistance
F	Faraday Number
V	Volume
P	Power
ρ_w	Density of workpiece
Subscript	
MRR	Metal Removal rate
Max	Maximum
Cm	Centimeter
ECM	Electrochemical Machining
ECMEM	Electrochemical Machining Etching Mask
Wt	Metal removal rate per weigh/gm
W_i	Initial weight
W_f	Final weight
Dc	Direct current
IEG	Implementation of the inter electrode gap
NTM	Non-traditional machining
SR	Surface roughness

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