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EXPERIMENTAL INVESTIGATION ON ELECTROCHEMICAL MACHINING PARAMETERS

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ABSTRACT: - The inherent characteristics of electrochemical machining (ECM) have large scale of advantages over the traditional machining technologies. ECM has been employed in this work to machining low carbon AISI1005 steel. Such technique is used to remove the electrical conductive material via a controlled electrochemical anodic reaction regardless of the metal mechanical properties. The considered experiments were conducted to study the effects of process parameters such as applied voltage, electrolyte flow rate, current density on all of weight loss, dissolution rate and material removal rate (MRR) in sodium chloride aqueous solution. The results stated that, the weight loss is in general increased with the voltage and the flow rate as its maximum value was 9.23 g and 5.35g respectively. Increasing the current density has led to obtain maximum MRR and dissolution rate of 0.248g/min and 1.59 mm/min respectively. The results showed that there was an enhancement in the MRR and the dissolution rate so as to be 66.8% and 49.3% respectively.
Keywords: Electrochemical Machining, Metal Removal Rate, Electrolyte.

1- INTRODUCTION

The new concept of manufacturing mainly focuses on non-conventional energy sources like sound light, mechanical, chemical, electrical, electrons and ions. Among these techniques, electrochemical machining (ECM) had been improved at first in the Soviet Union (1).With the industrial and technological growth, this technique took the interest in the development of harder and more difficult to machine materials. Recently, ECM is well considered in shaping ferrous and non-ferrous metals due to the large scale of its advantages such that; no effect of mechanical stress, a priori no thermal effect, excellent surface finish, independence of hardness or brittleness of the used material, no process related tool wear and flexible capability of complex shapes designing (2,3). Although, electro chemical machining considered to be a complex process – interpretation and modeling requires detailed knowledge of corrosion, passivation, interface kinetics, material science, crystallography, fluidics and electronics (4). Even more, metal surface quality is observed to be important requirement in the electro chemical machining process due to its effect on the performance of the produced part. The characteristics of machined surfaces have significant influence on the ability of the material to withstand stress, temperature, friction and corrosion (5&6).

The synopsis of ECM represents a specific anodic dissolution of materials. It can be explained such that, the work piece is connected to be the anode and the tool to be the cathode. A highly conductive electrolyte is pumped through the gap between the electrodes with relatively high speed. Electrode gap is considered during the machining process and the material of the work piece dissolves anodically (2). Finally, the inverse shape of the tool is generated in the work piece. Common electrolytes, aqueous solutions of sodium nitrate or sodium chloride, are considered in the experiment. (1). However, ECM is widely proved technique in machining tasks involving intricate shapes as well as in machining of very hard or brittle materials which are difficult or impossible to machine by traditional machining. In fact, it is now routinely used for the machining of aerospace components, critical deburring, fuel injection system components, ordnance components etc. it is also most suitable for manufacturing various types of dies and moulds [7-9].

of importance, many of studies have been agreed with the topic considered in this wok herein. This has been achieved in order to investigate the improvement in the electro chemical process performance in terms of metal removal or dissolution. Chakradhar and Gopal [10] performed ECM process on EN31 steel taking into account all of electrolyte concentration, feed rate and applied voltage as a parameters that affect the process significantly. They have optimized the multi response or in another word the output of the considered experiments; i.e. MRR, overcut, cylindricity error and surface roughness using grey relation analysis. Neto et al. [11] have studied the intervening variables in ECM. In this study the process parameters were represented by electrolyte flow rate, voltage and feed rate wherein the responses were roughness, metal removal rate and the over-cut. The importance of ECM process parameters such that; feed rate, voltage and electrolyte flow velocity have been discussed clearly by Rao et al. [12]. The study has been carried out to investigate the mentioned process parameters on metal removal rate, tool service life, geometrical dimensions accuracy and even the machining cost. Metal removal rate and ECM accuracy have been studied by Bhattacharyya et al. [13]. This has been investigated due to consider the tool vibration as significant parameters that affect the copper machining performance [6].

2. EXPERIMENTAL WORK

2.1 ELECTROLYTE, TOOL AND SPECIMEN METALS SELECTION

A square block of 25 mm x 25 mm and 3 mm thickness made of AISI1005 low carbon alloy steel is chosen as work-piece wherein an AISI4340 stainless steel rod of diameter 5mm has been chosen as a tool in this work. It is commonly serves in many automotive applications like structure or even in gates and railings, etc. The Chemical composition for the AISI1005 workpeice and the rod are listed in Table1. All the considered specimens were grinded using SiC paper (up to P1200) and then they were polished to be as a mirror-like surface using diamond suspension.

The electrolyte Solution has been selected to be NaCl and water, since it has no passivation impact on the workpiec surface. Before each machining process the workpiece has been painted to prevent any corrosion that occurs on the workpiece surfaces, which affects the weight of workpiece that was used to calculate the actual metal removal. The weight of workpiece is calculated by using digital gauge before and after the ECM operation to calculate the actual weight loss, metal removal rate (MRR) and dissolution rate.

2.1 ECM SETUP

The main components of ECM apparatus, which is manufactured by the researcher team for this experiment, is consisting of a process feeding system, Electrolyte pump , Flow meter, Electrolyte tank, reaction chamber and Power supply. The reaction chamber includes cathode tool and anode workpiece. The work piece was installed in the machining chamber fixedly. The cathode tool made vertical up/down movement with the driving of feeding system. Electrolyte was pumped through the machining gap from the channel which is inside the chamber. During the process, cathode tool made the feed motion toward the workpiece and the material were removed continuously. The experimental setups of ECM can be shown in Fig. 1.

2.3 MACHINING PROCESS

Electrochemical machining (ECM) is classified as nontraditional machining process in which the material is removed due to anodic dissolution mechanism during an electrolysis process [14, 15]. A D.C. voltage (10-20 volts) is applied across the inter-electrode gap between pre-shaped cathode tool and an anode workpiece. The electrolyte NaCl aqueous solution flows at high speed (9-12.5 l/min) through the inter-electrode gap (1 mm). The current density is usually 0.5 to 1.1 Amperes per mm square. The anodic dissolution rate, which is governed by Faraday's laws of electrolysis, depends on the electrochemical properties of the metal, electrolyte properties and electric current/voltage supplied (16).

In this machining process, chemical reactions occur at all of cathode, anode and in the electrolyte wherein the electrolysis process which takes place at the cathode liberates hydroxyl ions and free hydrogen. The electrolyte and water undergoes ionic dissociation, as shown below, when potential difference is applied and hence the electrolyte dissociation and NaCl dissolution results reveal to:-

$H_2O \rightarrow H^+ + OH^-$ (1)

$NaCl \rightarrow Na^+ + Cl^-$ (2)

At the anode, the iron atoms will come out of the anode (work piece) and hence Fe changes to Fe^{++} by losing two electrons as:

$Fe \rightarrow Fe^+ + + 2e^-$ (3)

The result of these electrochemical reactions leads that, iron ions combine with other ones to precipitate out as iron hydroxide, $Fe\ (OH)_2$.

$Fe + 2H_2O \rightarrow Fe\ (OH)_2 + H_2$ (4)

The ferrous hydroxide may react further with water and oxygen to form ferric hydroxide, Fe(OH)3.

$4Fe\ (OH)_2 + 2H2O + O_2 \rightarrow 4Fe(OH)_3$ (5)

In the electrolyte, iron ions combine with chloride ions so as to form the iron chloride and in the same way the sodium ions will combine with hydroxyl ions and hence leads to the formation of sodium hydroxide as a result.

$Na^+ + OH^- = NaOH$ (6)

In practice, $FeCl_2$ and $Fe(OH)_2$ will be formed and get precipitated in the form of sludge. Therefore, it is possible to observe that the work piece gets gradually machined and gets precipitated as the sludge. Furthermore, no coating presence on the tool, only hydrogen gas evolves at the cathode (tool). Due to the desired metal-electrolyte combination, electrolysis has involved the dissolution of iron, from the anode, and the generation of hydrogen, at the cathode. . This process resumes and the tool reproduces its shape in the workpiece (anode) (17).

2.3 THEORITICAL CALCULATIONS

The MRR can be calculated according to (18):-

$$MRR = \frac{W_b - W_a}{time} \quad \left(\frac{g}{min}\right) \qquad (7)$$

Where

W_b is the weight of the workpiece before carrying out the machining process and W_a is the weight of the workpiece after carrying out the machining process

The dissolution rate can be calculated in terms of :-

$$MRR\left(\frac{cm^3}{sec}\right) = \frac{MRR(g/sec)}{\rho} \qquad (8)$$

$$Dissolution\ rate = \frac{MRR\ (cm^3/sec)}{A} \qquad (9)$$

Where A is the area of the cathode.

3. RESULTS AND DISCUSSION

3.1 EFFECT OF VOLTAGE ON WEIGHT LOSS

Figure 2 shows the relationship between the weight losses that occur in the specimens versus the consuming time. This has been carried out when the voltage increased for the three curves shown in the figure. In fact, each curve indicates five experiments at certain voltage. The conditions for these experiment were represented such that; machining gap is (1mm), machining time (10min), electrolyte concentration (3%NaCl), electrolyte temperature (35˚C), and electrolyte flow rate (12 l/min). The voltage, as a parameter that affects the weight loss, has been selected to be 10V, 15V and 20V in this work. According to figure 2, the results stated that the value of the weight loss is in general increased with increasing the time. This might be explained due to the fact that , the ECM process starts at some A/cm^2 and the current density increases almost linearly with potential for currents >5 A/cm^2 [19-21]. Hence, at V=10 maximum weight loss has been obtained to be 8.13 g for the five experiments considered herein. Much enhancement in weight reduction can be obtained when the voltage is 15V and thus this will lead to maximum weight loss of 8.98 g. This has been carried out because the increment in the voltage can lead to further increase in the current density and thus more reduction in the weight can be obtained as a result. At V = 20, a hole is obtained in the specimen due to this corrosion process. This has led to obtain a maximum weight loss of 9.23g or otherwise the machining process can stop. More confirmation for the results represented in figure 2, can be obtained in terms of the visual inspection as it can be shown in figure3. This indicates the steps that involve the weight loss after every 10 minutes as this leads to reach the required machining process (hole) as a final step.

3.2 EFFECT OF FLOW RATE ON WEIGHT LOSS

Figure 4 illustrates the relation between the weight loss and the time in terms of different electrolyte flow rates 8.5, 11 and 12.5 l/min. From the conducted experiment, weight loss seen to be increased with the time for all cases of the flow rates as the trend might be different for each case. In fact, higher flow rates can lead to larger amount of weight reduction as compared to the lower flow rate. This might be attributed to the fact that, higher flow rate can significantly remove the hydrogen bubbles from the cathodic grooves resulting in an increased ionic strength and therefore more effective metal removal from the anode (workpiece) can be obtained. For that, maximum weight loss of about 5.35g can be obtained when the flow rate is 12.5 l/min. Whilst, when the flow rates have decreased to be 11 l/min and 8.5 l/min still a considerable weight reduction in the workpiece can be obtained to be 4.91g and 3.68g respectively.

Furthermore to this, the flow rate effect on the specimens can be seen visually in figure 5 as the material removal is clearly evident. Of importance, much enhancement in the whole surface finishing can be obtained as the flow rate has increased even more and this has been shown in figure 6 clearly.

3.3 EFFECT OF CURRENT DENSITY ON THE MRR AND THE DISSOLUTION RATE

The feasible relation between the metal removal rate (MRR) versus the current density can be represented in figure 7. Accordingly, the current density found to be as a prominent factor that affect the machining process or in other word the value of the MRR. Therefore, maximum MRR of 0.27 g/min can be obtained due to maximum current density of (1.1 A/mm2). This might be explained due to Faraday's law which states that the MRR is proportional to the machining current as this necessary to cause the required enhancement of MRR. Or in other word the increase in applied voltage leads to an increased current density in the inter-electrode gap (IEG), and hence MRR increases. Maximum enhancement in the MRR found to be (66.8%). This has been calculated in comparison to the minimum value of MRR 0.16 g/min when the current density is 0.51.

From different point of view, the current density found to affect the dissolution rate significantly as this can be seen in figure8. In fact, the relation between the current density and the dissolution rate tend to be close to the relation between the current density and the MRR. Hence the dissolution rate is in general increased by increasing the current density. Due to calculation prospective, maximum dissolution rate obtained to be 1.592 mm/min when the current density is 1.02 A/mm^2 or this leads to a considerable enhancement in the dissolution rate of about 49.3% as a result.

3.5 EFFECT OF FLOW RATE ON MRR AND DISSOLUTION RATE

Figure9 and figure10 show the effects of electrolyte flow rate on the MRR and dissolution rate respectively. The results reveal that the fluid flow rate has a significant impact on the selected objectives as obtained in the patterns of both of MRR and dissolution rate. For all electrolyte flow rates, the MRR and the dissolution rate found to be increased with the flow rate of the electrolyte in the ECM. Hence, maximum MRR value has obtained to be (0.267g/min) when the flow rate is (12.5l/min) whereas the value of the dissolution rate was about 1.72 mm/min when the flow rate is (12.5l/min).

4. CONCLUSIONS

This experimentation study has been carried out to investigate the process parameters (voltage, electrolyte flow rate and current density) impact on weight loss, dissolution rate and MRR by using electrochemical machining of AISI1005 material. According to the considered results it can be concluded that, the weight loss of AISI1005 is increased significantly by increasing, voltage and electrolyte flow rate. Furthermore to this, the MRR and the dissolution rate were both increased with increasing the current density and the flow rate as the trend might be different for each case.

The following conclusions can be drawn from the above investigations: Increase in applied voltage leads to an increased current density in the inter-electrode gap (IEG), and hence MRR increases. The increment in electrolyte flow rate can result in more mobility of ions and this increases the speed of the chemical reaction or otherwise leads to more MRR.

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List of symbols and abbreviations

ECM	Electrochemical machining
MRR	Metal removal rate
IEG	Iter-electrod gap
Q	Flow rate
V	Voltage
Wa	the weight of the workpiece after carrying out the machining process
Wb	the weight of the workpiece before carrying out the machining process and

Table.1 represents the chemical composition of workpiece (AISI 1005) and tool (AISI4340).

sample	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Al%	Co%	Cu%	Fe%
AISI 1005	.046	.04	.274	.09	.013	.019	.002	.019	.014	.001	.013	Bal
AISI4340	.387	.124	.72	.008	0.0	.65	.2	1.55	.021	.008	.067	Bal

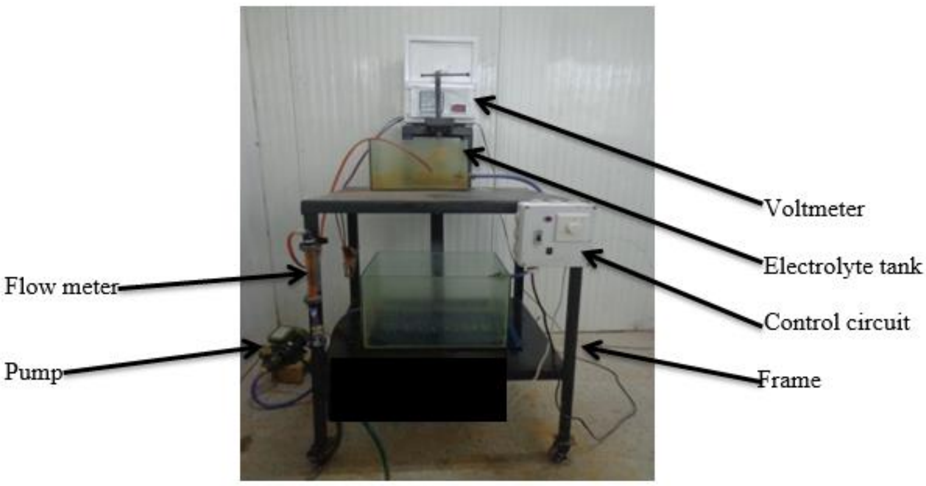

Fig.1 shows the ECM manufactured device

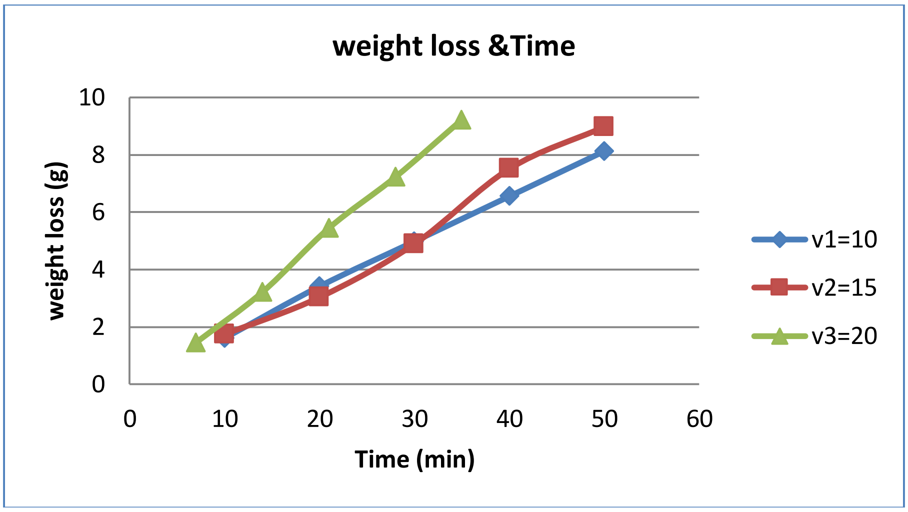

Fig. 2 shows the weight loss values in terms of different voltages

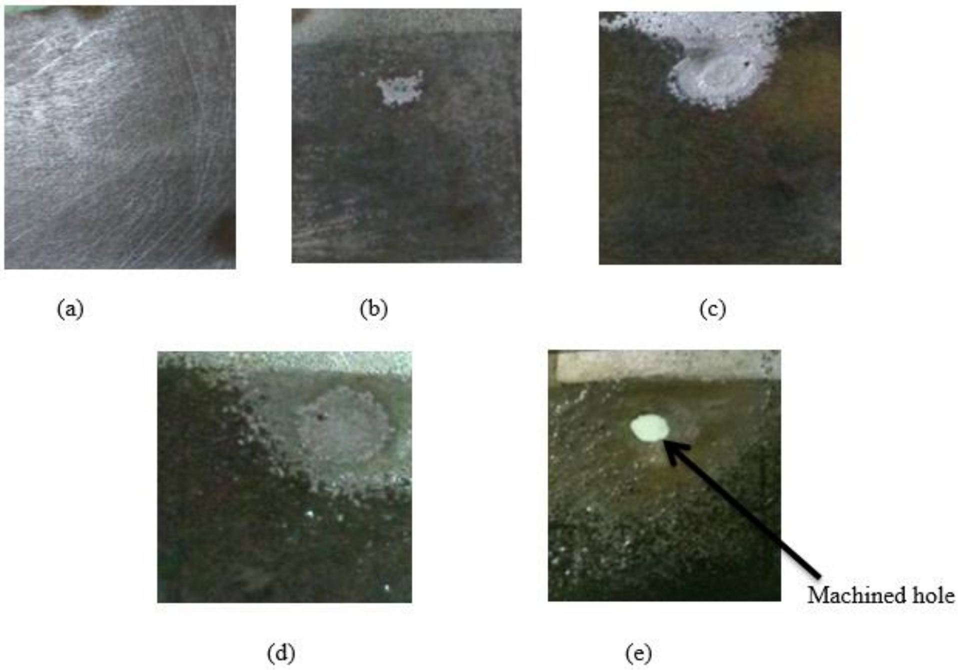

Fig.3 shows the specimen machining in terms of voltage consideration: (a) as received workpiec, (b) after 10 minutes, (c) after 20 minutes, (d) after30 minutes,(e) after 40 minutes.

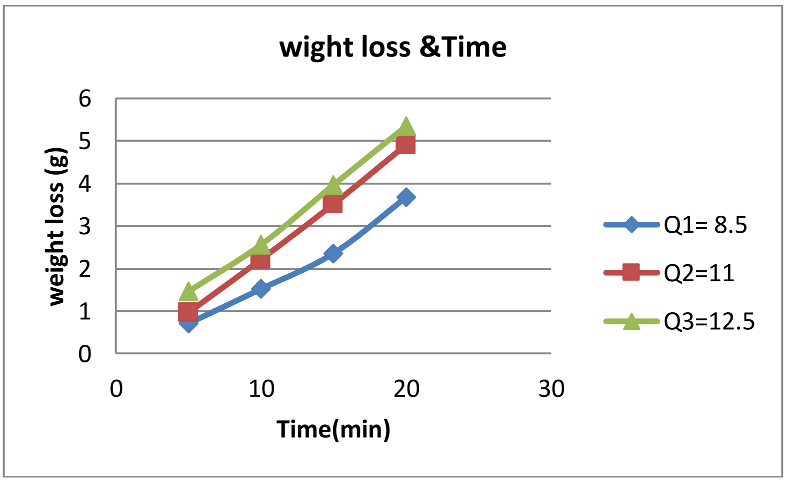

Fig.4 shows the weight loss values for different electrolyte flow rates

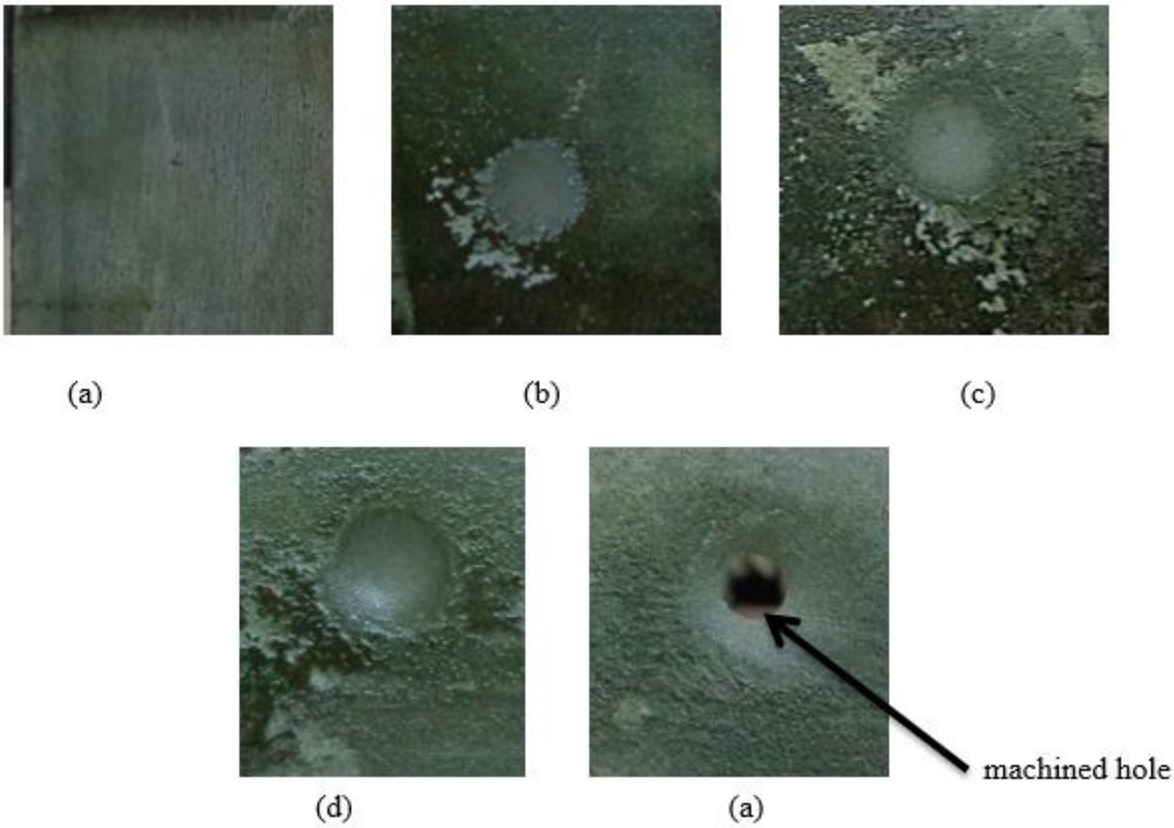

Fig.5: shows the specimen machining in terms of flow rate: (a) as received workpiec, (b) after 5 minutes, (c) after 10 minutes, (d) after15 minutes, (e) after 20 minutes.

Fig.6: shows smooth hole shape at excessive of flow rate.

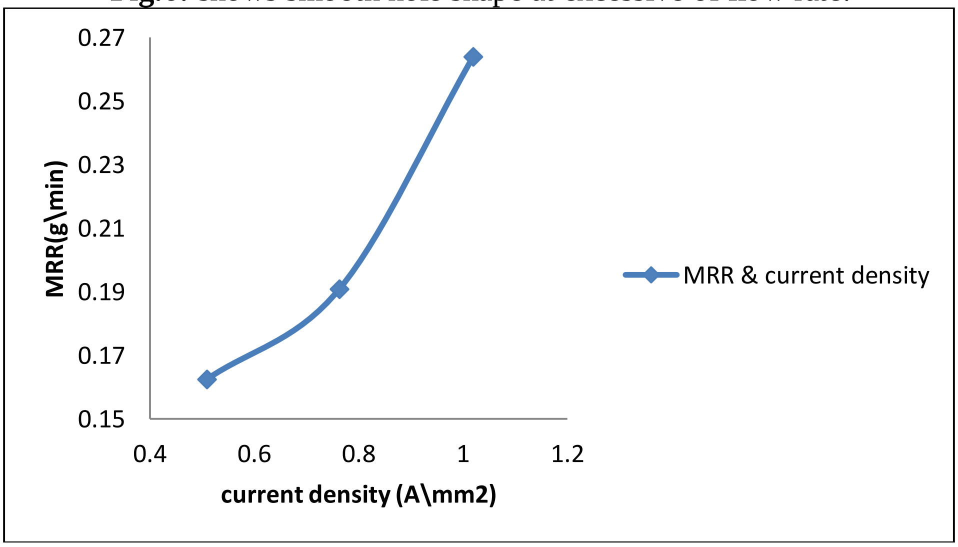

Fig.7 shows the effect of the current density on the MRR

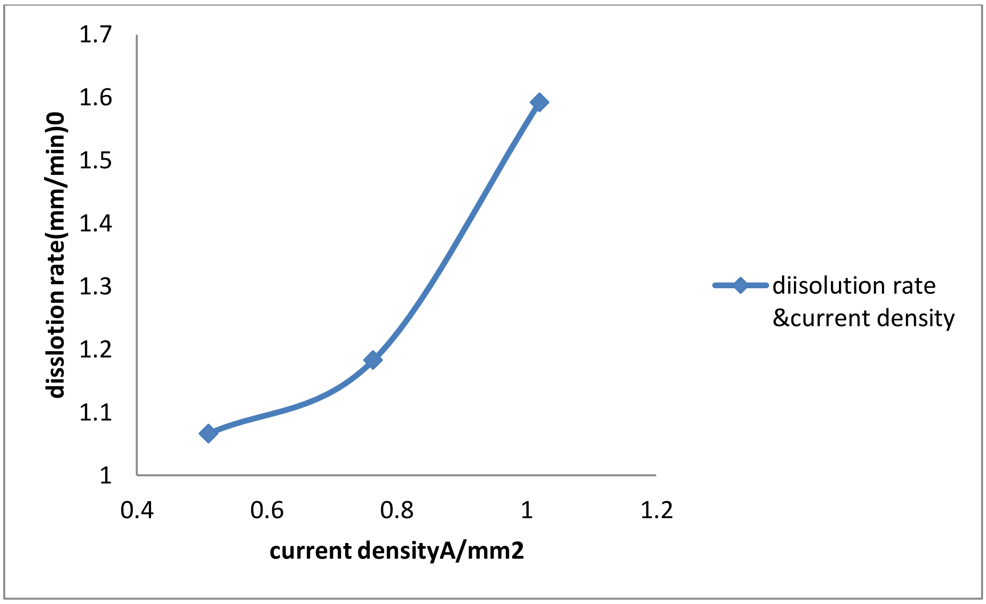

Fig. 8 shows the effect of current density on the dissolution rate

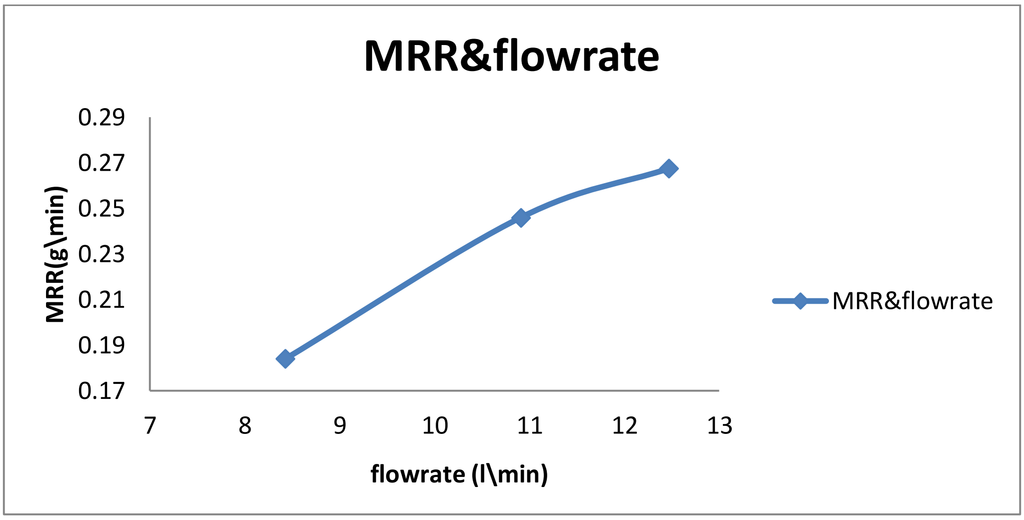

Fig.9 shows relationship between MRR and flow rate

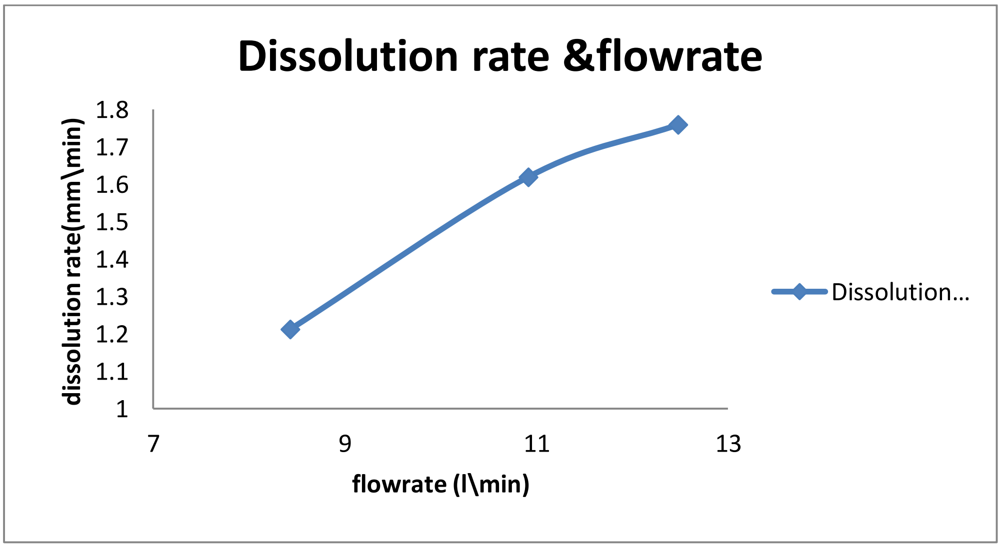

Fig.10 shows relationship between dissolution rate and flow rate

دراسة عملية حول متغيرات التشغيل الكهروكيميائي

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الخلاصة

ان الخصائص الكامنة في التشغيل الكهروكيميائي (ECM)لها نطاق واسع من المزايا بالمقارنة مع تقنيات التشغيل التقليدية. تم توضيف التشغيل الكهروكيميائي في هذا البحث لتشغيل فولاذ منخفض الكاربون نوع AISI 1005 .حيث ان التقنية استخدمت لازالة المعدن الموصل كهربائيا بواسطة تفاعل انودي مسيطر عليه بغض النظر عن الخصائص الميكانيكية للمعدن المشغل. التجارب العملية اجريت لدراسة تاثير عوامل التشغيل مثل الفولتية المسلطة ,معدل جريان المحلول وكثافة التيار على كل من الفقدان في الوزن, معدل الاذابة ومعدل المعدن المزال في محلول كلوريد الصوديوم. النتائج بينت ان الفقدان في الوزان يزداد بشكل عام مع زيادة كل من الفولتية ومعدل جريان المحلول الكهربائي حيث بلغت اقصى قيمة له9.23g و 5.35g على التوالي . زيادة كثافة التيارقد دعت الى الحصول على زيادة قصوى في معدل المعدن المزال ومعدل الاذابة لتصل الى 0.248g/min و 1.59 mm/minعلى التوالي. كذلك ان النتائج بينت معدل التحسن في معدل المعدن المزال ومعدل الاذابة لتصل الى 66.8% ,49.3 % على التوالي.

الكلمات المفتاحية: التشغيل الكهروكيميائي, معدل المعدن المزال, محلول كهربائي.