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Prediction of Metal Removal Rate and Surface Roughness in Electrochemical Machining (ECM)

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ABSTRACT

Electrochemical Machining (ECM) is a relatively important method of removing metal by anodic dissolution. In this research the ECM was used to remove the metals from the internal hole of the workpiece.The tool used was made from brass. This research focuses on the parameters of the change in gap size, the change in current density, and the change of the tool roughness on the Material Removal Rate (MRR), and Surface Roughness of the workpiece. The Statistical Package for Social Science (SPSS) software was used to predict the results. It was found that for the surface roughness the coefficient of determination of the prediction was (0.982) and the accuracy of prediction (97.15%). For the Material Removal Rate in (g/sec) units the coefficient of determination of predicts was (0.991) with accuracy of prediction (98.29%).

Keywords: current density, tool roughness, metal removal rate, surface roughness, SPSS software.

تنبأ لقيم كمية ازالة المعدن والخشونة السطحية عند التشغيل الكهروكيميائي(ECM)

الخلاصة

يعتبر التشغيل الكهروكيميائي (ECM) من اهم الطرق المهمة لازالة المعدن بطريقة الانحلال الانودي. في هذا البحث استخدمت طريقة (ECM) في ازالة المعدن لتوسيع الثقب الموجود في القطعة المشغلة بأستخدام عدة من البراص. تركزت الدراسة على المتغيرات وهي التغير بحجم الفجوة بين العدة والشغلة ، تأثير كثافة التيار ، إضافة إلى تأثير خشونة سطع الأداة على كمية المعدن المزال (MRR) وخشونة سطح المشغولة.

عند استخدام برنامج (SPSS) من خلال فرض معادلة تعطي نواتج مقاربة للنواتج التي وجدت بالتجارب العملية حيث وجد ان الفرضية لقياس خشونة السطح من خلال حساب معامل التحديد (coefficient of determination) يساوي (0,982) ودقة التنبؤ (97,15%) عند حساب معدل ازالة المعدن بوحدات (غم / ثا) فأن معامل التحديد يساوي (0,991) ودقة المعادلة (98,29%).

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INTRODUCTION

Electrochemical machining process has no contact between the tool and the workpiece which is maintaining an electrolyte between the workpiece (anode) and tool (cathode) across a small gap size between them, as shown in Fig (1)[1]. ECM removing metal by anodic dissolution method and this process have no cutting forces and stresses because the process depending on electrical conductivity of materials and chemical reaction between the electrolyte and the workpiece[2]. ECM process has many of advantages which are the ability to machine economically without striation marks left by milling cutter. By preparing one set of cathode tools, it is possible to machine many roughly formed components to within close limits of the desired contour. For this reason, gas and steam turbine blades are machined by this method, machining ability is independent of the mechanical properties of the workpiece materials. No thermal damage occurs to the workpiece structure. Produce stress free surface. High surface finish [3].

Many of researches used different types of software programs to predict the results of the important parameters that effecting on the ECM process, Dayanand ***S. et al,.2005*** [4] developed mathematical model to express the effect of the ECM process parameters (feed rate, voltage, pulse on time, duty cycle, and bare tip length of the tool) on the metal removal rate by using ANOVA regression. ***Umasankar Mallick ,et al.,(2009)*** [5] used Taguchi Design in statistica software or called SN ratio to study the influence of ECM machining parameters such as (feed rate, applied voltage, conductivity and flow rate) on the over cuts in length, width and height of the specified cavity by using tool as U – shape, This method utilize two-, three-, and mixed-level fractional factorial designs. Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes. ***Yu Zhang., (2010)*** [6] developed a linear regression model for predicting current efficiency of the ECM process by using The Statistical Package for Social Science SPSS. These effects are (current density, type of electrolyte, and electrolyte flow rate) on current efficiency under different experimental conditions.so this research study a new relation between metal removal rate and surface roughness.
This research was focused on gap controlling method which play an important factor in electro chemical machining by choice sample as shown in Figure (5).

THEORETICAL PROCEDURE

To minimize the number of experiments many prediction techniques are used[4]. These Techniques are used to determine the relationship between various process parameters and exploring the effect of these process parameters on the Material Removal Rate (MRR), and the surface roughness(Ra)[7]. The Statistical Package for Social Science (SPSS) has many facilities in construction of predictive models which have nested data structure [8, 9].

The (SPSS) can predict the relationship between the parameters by using regression analysis which is given by the relationship between the dependent variable and one or more of the independent variables. If the relation has one independent variable, the relation would be (simple regression model). While if the relation has more than one independent variable, the relation would be (multiple regression model) [10, 6].

For this research, there are three parameters (gap size, current density, and tool roughness), for this reason the multiple regression model is usefull to pridect Material Removal Rate (MRR) , the surface roughness (Ra). The intial model that was invesigated in general for three factors analysis for this study was:-

$$Y = \alpha + \beta_0 X_1 + \beta_1 X_2 + \beta_2 X_3 + \beta_3 (X_2X_3) \ldots\ldots\ldots(1)$$

Where Y is surface roughness , material removal rate, α is constant or called intersection parameter, β_0 *to* β_3 is coeficients for independent variables or called partial regression. X_1 is gap size (mm),X_2 is current density (Amp/ cm^2), and $X3$ = tool roughness (µm).

EXPIREMENTAL PROCEDURE

In this research used the workpiece as shown in table(1a,b) and studied the effect of the parameters gap size (1, 1.5, 2, 2.5, 3mm), current density (2.448, 2.856, 3.2647, 3.6728 Amp/cm^2), and tool roughness (3.384, 2.65µm) on the metal removal rate (MRR), surface roughness experimentlly by using these equations[6]:

$$Actual\ MRR = \frac{wb - wa}{Time} \quad (g/sec) \qquad \ldots.(2)$$

Where *Wb is* weight the workpiece before ECM operation (g), and *Wa is* weight the workpiece after ECM operation (g)

To compare the result of the experimental work with the output of the SPSS programe it had be taken the same parameters that studied experimantlly as input as table (2).From *(SPSS)* software and after input of variables x1, x2, x3, x2x3 and (Ra) , (MRR) .

Surface roughness device: Device was used to measure work surface as shown in Figure (7) using probe slide over surface and give roughness (Ra) reading .

- Click on the following: *Analyze => Regression => Linear.*
- *The Linear Regression* window should appear as in Fig (2).
- Select measured surface roughness (Ra) for example and click it over to the *Dependent* box (dependent variable). Next, select the variables gap size, current density, tool roughness and click them over to the *Independent(s)* box (independent variables).
- Under *Method,* be sure that *Enter* is selected.

- Click *Statistics* then click *Estimates* (under *Regression Coefficients*)**,** then click *Model fit* and *Descriptive* then click *Casewise diagnostic* and *All cases* **(** under *Residuals*) **,** as shown in fig (3)**.**
- Click *Continue***.**
- Click *OK.*

Finally, the predicted values will appear for both surface roughness and Material Removal Rate with their measured values.

RESULT AND DISCUSSION

To use the package SPSS to estimate relationships between the three parameters (gap size, current density, and tool roughness) to give the results for both surface roughness and the Material Removal Rate by predict models in (SPSS) software.

This is statistical model for prediction of surface roughness (Ra) and Material Removal Rate (MRR) created by regression function in (SPSS) software and the results are:-

- By using the multiple regression model in equation(1) on the surface roughness (Ra), the coefficients of the independent variables were obtained and the multiple regression equation would be:-

$$Y = 1.668 + 1.177 X_1 - 0.782 X_2 + 0.485 X_3 + 0.019 X_2 X_3$$

Where *(Y)* in this equation is the surface roughness and the results of this regression are shown in table (3). The model summery shown in table (4) contains the important indicators called the coefficient of determination (R^2) and the standard error of the estimate, (R^2) considered as the measurement of how the model is perfect.

$$R^2 = \frac{regression value}{(regression + residual) values} \qquad \ldots(3)$$

If the (R^2) is approximately equal to one the model is excellent that means it must be ($0 \le R^2 \le 1$). For the surface roughness the (R^2) is 0.982 that mean the model is perfect.

The standard error of the estimate is the measurement of the dispersing of the magnitude (in the normal probability scatter plot between the prediction values in X – axis and the residual values in Y – axis as shown in fig (4) from the oblique line, if the standard error of the estimate is too small the model is excellent. For the surface roughness the standard error of the estimate is 0.164063. The accuracy of the prediction for the surface roughness is (97.15%).

The results of the surface roughness from the regression model is given in table (5) as predicted values (by the SPSS model) and the true values (from experiments), the difference between the two values for the three cases were too small as shown in fig (5) for more explicit.The residual values are the difference between the measured and the predicted values which must be not more than (1) or less than (-1) in the prediction model.

- By using the multiple regression model in equation(1) on the Material Removal Rate (MRR), the coefficients of the independent variables were obtained and the multiple regression equation would be:-

$Y = -0.011 - 0.001\,X_1 + 0.01\,X_2 + 0.0001\,X_3 - 7.112*10^{-5}\,X_2\,X_3$

Where Y in this equation is the Material Removal Rate in (g/sec) units and the results of this regression is shown in table (6). From the model summery shown in table (7) For the Material Removal Rate the (R^2) is 0.991 that mean the model is perfect.

The standard error of the estimate for the Material Removal Rate is 0.00045704 and the accuracy of prediction of the material removal rate in (g/sec) is (98.29%), the normal probability plot is shown. The results are too close to the oblique line as in fig (6).

The results of the Material Removal Rate from the regression model are given in table (8) as predicted values (by the SPSS model) and the true values (from experiments), and the difference between the two values for the three cases are too small as shown in the fig (7) for more explicit. Also from the table (8) it is found that the residual values are between (1) and (-1).

CONCLUSIONS

· Increasing current density lead to increase surface roughness and metal removal rate.

·Gap size has a grat influence in metal removal rate , when gap size (1mm) give a metal removal rate equal to (0.015g/sec) but increasing gap size to (2mm) lead to reduction metal removal rate to (0.014g/sec).

· (SPSS) software is used to predict the effect of changing gap size, current density, and tool roughness on surface roughness of the workpiece, dissolution rate, and material removal rate (MRR). The results obtained when approximately equal to that of the experiments and the accuracy was (97%) for surface roughness, and (98%) for MRR.

·When using smoother tool both characteristics; material removal rate (MRR) and surface roughness have the same in results in material removal rate (MRR) and more surface finish in machining surface arrived to (23%) when compared with the results at a rougher tool (3.384µm).

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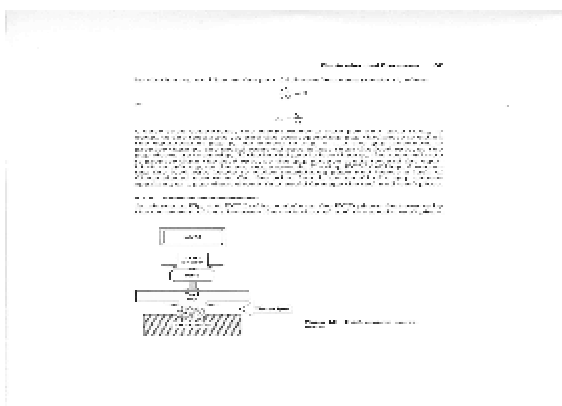

Figure (1) Scheme of ECM process

Table (1a) The material specification

Material standard	DIN system
Material of the workpiece	Medium carbon steel (Ck35)
Steel group	Special structural steels
Designation symbol	CK35
Material number	1.1181
Density of the alloy	7.85 g/cm^3

Table (1b) Chemical composition of the workpiece

element	C	Mn	Si	P	S	Ni	Cr	Mo	CU	AL	**Remain**
Wt%	0.35	0.81	0.19	0.011	0.023	0.3	0.07	0.01	0.02	0.05	98.436

Table (2) Experimental conditions that affecting on MRRg and surface roughness.

Gap size (mm)	**Current density (amp/cm^2)**	**Tool Roughness (µm)**	**Surface roughness (mm)**	**Metal removal rate (g/sec)**
1	2.856	3.384	2.6	0.015
1.5	2.856	3.384	3.05	0.0146
2	2.856	3.384	3.62	0.0141
2.5	2.856	3.384	4.32	0.0133
3	2.856	3.384	4.88	0.0126
1	2.4485	3.384	2.687	0.0116
1	2.856	3.384	2.49	0.015
1	3.2647	3.384	2.08	0.0183
1	3.6728	3.384	1.855	0.0233
1	2.4485	2.65	2.325	0.0116
1	2.856	2.65	2.076	0.015
1	3.2647	2.65	1.77	0.0183
1	3.6728	2.65	1.417	0.0233

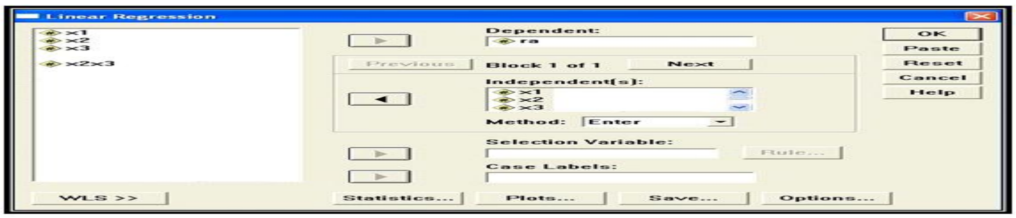

Figure (2): Linear Regression

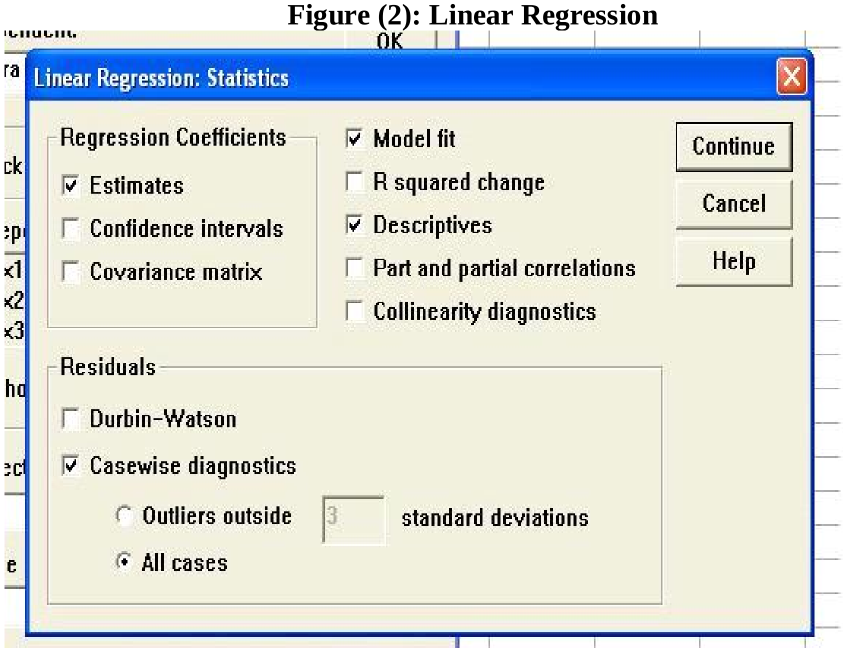

Figure (3): Linear Regression: Statistics

Table (3) Coefficients of the independent variables in multiple regression equation for the surface roughness

Symbol	**Independent variables**	**Un standardized Coefficients (β)**
Intersection parameters	constant	1.668
Gap size	X_1	1.177
Current density	X_2	-0.782
Tool roughness	X_3	0.485
	X_2X_3	0.019

Table (4) Model summery of the surface roughness

R.Square	Standard error of the estimate
0.982	0.164063

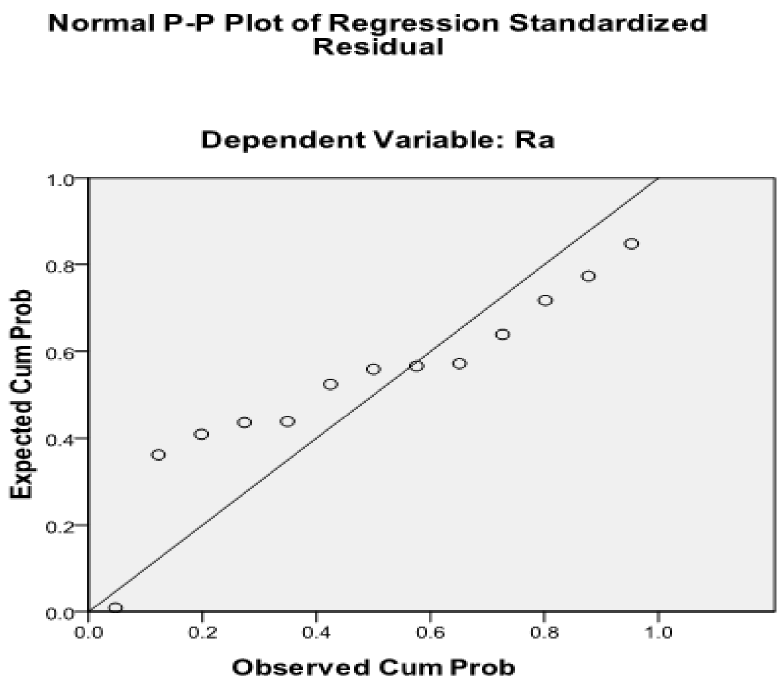

Figure (4) The normal probability plot of the surface roughness model

Figure (5) workpiece samples

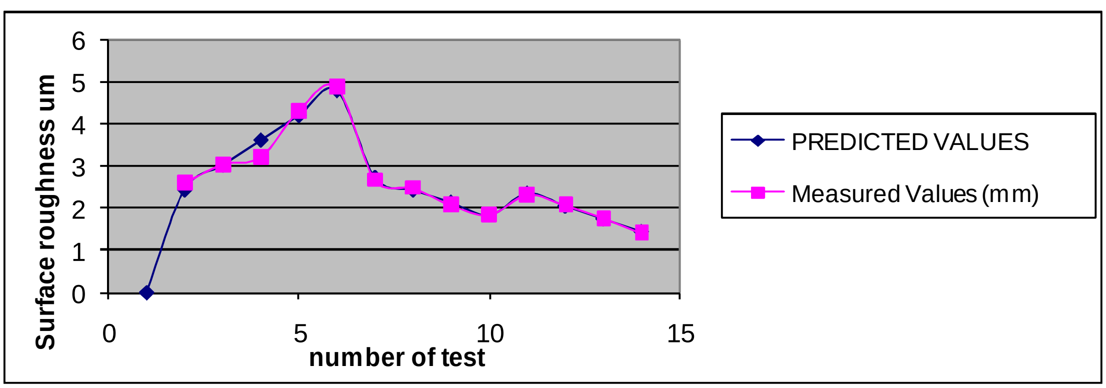

Figure (6) The difference between the measured and predict values in surface roughness model for the three operations

Table (5) the measured and predict values for the surface roughness model for three operations

MEASURED VALUES (μm)	PREDICTED VALUES (μm)	Residual Values
2.6	2.43153	0.168467
3.05	3.02002	0.029978
3.22	3.60851	-0.388511
4.32	4.19700	0.123000
4.88	4.78549	0.094511
2.687	2.72488	-0.037878
2.49	2.43153	0.058467
2.08	2.13819	-0.058189
1.855	1.84484	0.010156
2.325	2.35150	-0.026500
2.076	2.04850	0.027500
1.77	1.74550	0.024500
1.417	1.44250	-0.025500

Figure (7) Surface roughness device

Table (6) Coefficients of the independent variables in multiple regression equation for the material removal rate MRRg

Independent Variables	**Unstandardized coefficients (β)**
Constant	-0.011
X1	-0.001
X2	0.01
X3	0.0001
X2X3	-7.112E-5

Table (7) Model summery of the Material Removal Rate MRRg

R .Square	**Standard Error of the Estimate**
0.991	0.00045704

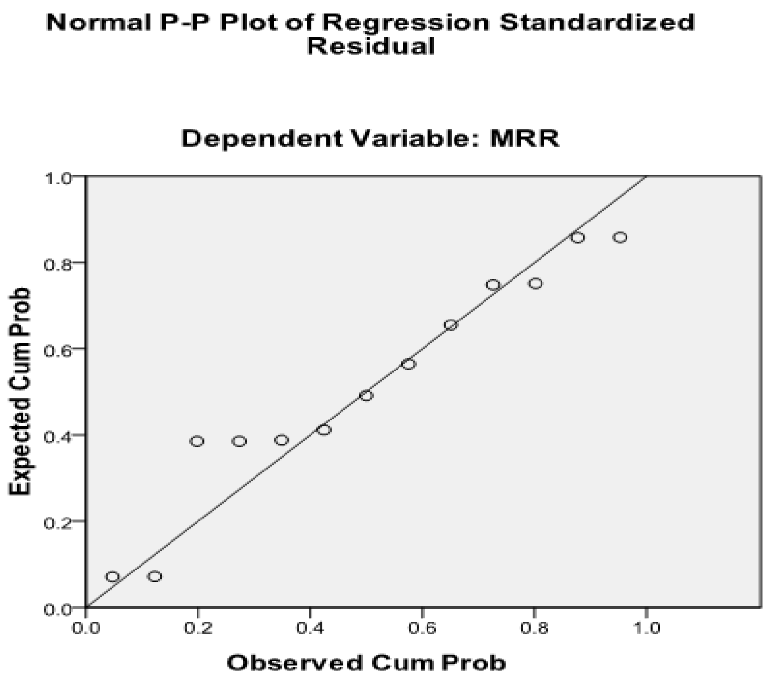

Figure (8) The normal probability plot of the material removal rate model in (g/sec) unit

Table (8) The measured and predict values for the material removal rate MRRg model for three operations

MEASURED VALUES (g/sec)	PREDICTED VALUES (g/sec)	RESIDUAL VALUES
0.01500	0.0151366479	-1.3664785E-4
0.01460	0.0145277652	7.2234766E-5
0.01410	0.0139188826	1.8111738E-4
0.01330	0.0133100000	-1.0000000E-5
0.01260	0.0127011174	-1.0111738E-4
0.01160	0.0113211947	2.7880529E-4
0.01500	0.0151366479	-1.3664785E-4
0.01830	0.0189633367	-6.6333668E-4
0.02330	0.022784407	5.1559232E-4
0.01160	0.0113251229	2.7487707E-4
0.01500	0.0150127511	-1.2751057E-5
0.01830	0.0190098750	-7.0987499E-4
0.02330	0.0228522510	4.4774897E-4

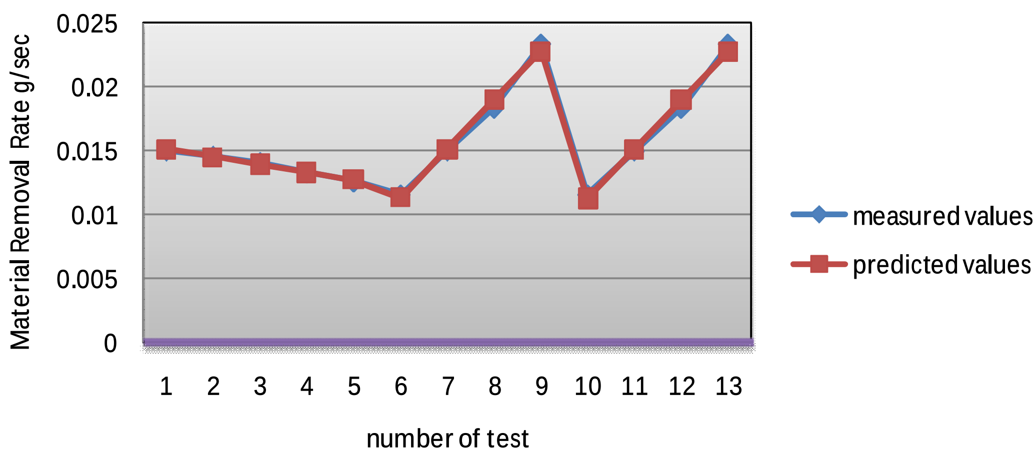

Figure (9)The difference between the measured and the predict values in metal removal rate model for the three operations.