Prediction of Particle size and Material Removal Rate of zinc oxide (Zno) during Electrochemical machining process

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Abstract:

Today zinc oxide play an important applications in industrial such as catalysts, rubber and concrete additives , medical , electrical , this paper was focused on machining zinc material by Electrochemical machining (ECM) which is based on the principle of Faraday's law .ECM is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the workpiece is anode and tool is cathode to remove the material from the workpiece (pure zinc) by using brass tool. This research deals that to investigate the effect of parameters (Current density, Gap distance, Electrolyte concentration) on Metal Removal Rate (MRR) and particle size of (Zinc oxide) sludge waste that precipitate from ECM. Response surface methodology (RSM) was used to predict the results. The results show that the predication accuracy of particle size is (99.54%) ,where the prediction accuracy for material removal rate is found to be (99.92%).

Keywords: Zinc Oxide , Electrochemical machining ECM, MRR, prediction, RSM .

Introduction:

.Zinc oxide (ZnO) is one of the most attractive oxide semiconductor materials with its unique physical and chemical properties, such as high chemical stability, high electrochemical coupling coefficient, broad range of radiation absorption, paramagnetic nature and high photostability, is a multifunctional material. the powder ZnO is widely used as an additive in numerous materials and products including ceramics , glass, cement, rubber, lubricants, paints, ointments, adhesives, plastics, sealants, pigments, food, batteries ferrites, Shuxi Dai et al (2013) [1] . ECM is the one of the unconventional machining process used for machining high-strength, heat resistant, extremely hard materials into complex shapes. ECM is a process based on the controlled anodic dissolution process of the work piece as anode, with the tool as cathode in an electrolytic solution. Its industrial applications have been extended to electrochemical drilling, grinding, deburring and polishing Saad .K.Shather etal (2017) study the influence of electro chemical parameters on machining of Zn and prove that increasing current lead to enhance metal removal rate while decreasing particle size of ZnO [2]. In electrochemical machining, the metal is removed by the anodic dissolution in an electrolytic cell in which work piece is the anode and the tool is cathode. The electrolyte is pumped through the gap between the workpiece and the tool, while direct current is passed through the cell, to dissolve metal from the workpiece [3]. Many researchers used various types of software programs to predict the results of the important parameters that influencing on ECM process are **S. C. Jayswal ,et al (2011)[4]** investigated the influence of different process variables and electrodes on the MRR and Ra of ECM on EN8 alloy steel component. In this study, Design of Experiment Method (DOE) has been employed to discover the effects of process variables (flow rate of the electrolyte, voltage and feed rate) and different electrodes (aluminum and copper) on MRR and Ra. The results obtained show that, Al Electrode has (45.9mm3/min) lower material removal rate than Cu Electrode (61.5mm^3/min).The (Cu) electrode gives lower surface roughness (0.58µm) than (Al) electrode (0.62µm). **S. Rama Rao,et al.,(2012) [5]** investigated the influences of process parameters (feed rate, voltage and electrolyte concentration) of electrochemical machining on the material removal rate of LM6 Al/5%SiC composites. Taguchi experimental design method was used to determine the process parameters. A regression analyses and analysis of variance (ANOVA) are employ to determine the optimal process parameter and to analyze the influence of these parameters on MRR. The confirmation experiment analysis for MRR has shown that Taguchi parameter design can perfectly verify the optimum cutting parameters, which are feed rate(0.3mm/rev),voltage(20V),and electrolyte concentration(30 g/l). The results show that the MRR increases with increasing of electrolyte concentration, voltage and feed rate, maximum MRR is (0.131 g/min) estimated by Taguchi's optimization method. **Neelam Kumar Verma (2013)[2]** studied the effect of machining responses of MRR, and SR of the mild steel specimen using a Cu electrode (a through hole of 4 mm) tool have been investigated for ECM process. The experiment was conducted under various machining parameters setting of (voltage, feed rate and electrolyte concentration. Taguchi design and RSM design was performed by using Minitab software, results are analyzed and these responses were partially validated experimentally. The results show that main effects of feed, voltage and concentration of electrolyte are (0.05848, 0.01649 and 0.01110) respectively, on MRR in mm3/min, in order of significance. MRR increases with the increase in feed. MRR slightly increases with increase in voltage and then decrease. MRR slightly decreases with increases in concentration then increases with increase in concentration. For MRR the mathematical model fits the data as (R^2) is 98.7%. In case of SR, the main effects of feed, voltage and concentration of electrolyte are 3.967, 2.200 and 0.800 respectively, on SR in µm, in order of significance. In which there feed rate is important factor and then voltage and then electrolyte concentration.

feed is the most influencing factor and followed then by voltage and last the concentration of electrolyte. SR increases with increasing in both of feed rate and voltage. However, the effect is less than the feed rate on SR but SR slightly decreases with increases in concentration. For SR the mathematical model fits the data as (R^2) is 94.1%. **C. Senthilkumar, et al (2013)[6]** aimed to find appropriate selection of manufacturing process conditions in one of important aspects in the die sinking Electrochemical Machining, as these conditions determine important characteristics such as Material Removal Rate (MRR) and Surface Roughness(Ra). In this study the effect of machining responses of MRR, and Ra of the LM25Al/10%SiCp composite have been investigated for ECM process. Experiments have been achieved to establish an empirical relationship between machining parameters (voltage, tool feed, electrolyte concentration) and responses in ECM process using RSM (Response Surface Methodology). The result shows that the increasing in applied voltage and tool feed rate increasing in current density in (IEG), and from here MRR increases. The Increasing in electrolyte concentration led to increases of MRR. Max increasing in MRR is 0.0634 g/min. For MRR the mathematical model fits the data as (R^2) is (90.31%).The increase in electrolyte concentration Ra decreases up to (25 gm/l) with further increase in electrolyte concentration, the property of the electrolyte changes and act as lower concentration leading to high surface roughness. Max decrease in surface roughness is (1.819 µm). For (Ra) the mathematical model fits the data as (R^2) is (91.44%).

Zinc oxide (ZnO) is an inorganic compound widely used in many applications such as in pharmaceutical, cosmetic, food, rubber, commodity chemical, painting, ceramic, .and glass industries.

Jinhuan Jiang etal (2018) also study the zinc oxide nanoparticles as one of the most important specially to improve the performance of high polymer in their toughness Because of the strong UV and intensity and anti aging, and other functions. absorption properties

Prediction Model

To minimize the number of experiments many prediction techniques are used. These techniques are used to determine the relationship between various process parameters and explore the effect of these process parameters on the Material Removal Rate (MRR) ,partical size [7]. In this research (RSM) is used to predict the partical size and Material Removal Rate (MRR).

Response surface methodology (RSM)

The response surface methodology (RSM) is a group of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objectives are predicting a response (output variable) which is influenced by many independent variables (input variables) [8].

The most popular applications of (RSM) are in the specific situations, where many input variables potentially affect some performance. Measurements or quality characteristics of the process. Thus quality characteristic or performance measure is called the response. The independent variables are the input variables and they are controlled by the scientist or engineer. The field of (RSM) consists of the experimental strategy for exploring the process or independent variables, empirical statistical modeling to develop an adequate approximating relationship between the yield and the variables of process and optimization methods for finding the values of the process variables that produce desirable values of the response [9].

RSM is used to determine the relationship between the different ECM process parameters like (current density, gap distance and concentration) and developing the influence of these parameters on the response (particle size and Metal Removal Rate(MRR)). A second order polynomial response surface mathematical models are developed. So as to study the influence of ECM parameters on the above-mentioned machining criteria. [10]

The second order polynomial response surface mathematical model, which analyses the parametric effects on the different response criteria, can be described as follows:

$$Yu=\alpha + C_1 X_1 + C_2 X_2 + C_3 X_3 + C_4 (X_1)^2 + C_5(X_2)^2 + C_6 (X_3)^2 \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

Where:

Yu= Particle size and Material Removal Rate MRR.

α=constant.

C_1 to C_6 = Coefficients for independent variables.

X_1= Current density (Amp/ cm^2).

X_2= Gap distance (mm).

X_3=Electrolyte concentration (g/l).

Regression analysis is performed by the use of design of experiments (DOE) where, is the corresponding response, e.g. particle size, MRR, produced by the various process variables of ECM [7].

Estimation of Experimental Material Removal Rate (MRR_{exp})

The actual material removal rate can be determined by [10]:-

$$MRR_{exp} = \frac{wb-wa}{Time} \text{ (g/sec or g/min)} \qquad \text{.... (2)}$$

Where:

MRR_{exp}: Experimental material removal rate.

Wb = weight the workpiece before ECM operation (g).

Wa = weight the workpiece after ECM operation (g).

The Effect of Machining Parameters on Particle size of Zinc Oxide:

The values of current density used for this experiments are (11.93, 15.91, 19.89, 23.87, 27.85) A/cm^2.The results are given in Table (1). It can be noted that the increasing in current density causes decreasing in particle size. When increasing current density the removal of the metal process more as the Faraday law, where the kinetic energy of particles Transmitted be high and that this rapid movement prevents particles conglomerate and thus be of smaller size. The values of gap distance used for this experiments are (0.5, 0.75, 1, 1.25,1.5) mm. Table (1) shows that the particle size increases with increase in gap distance. The increase in distance between tool and workpiece causes increase in volume of electrolyte which increases in Ohmic resistance of the electrolyte that causing decrease in current density due to increase in particle size. The values of electrolyte concentration used for this experiments were (100, 150, 200, 250, 300) g/l. The particle size decreases with increasing electrolyte concentration from (100-300) g/l. the cause of decreasing in particle size that when increases in electrolyte concentration due to increase electrical conductivity of the electrolyte which means increase in machining current that due to decrease in particle size.

The Effect of Machining Parameters on Material Removal Rate (MRR)

The value of current density used for this experiments are (11.93, 15.91, 19.89, 23.87, 27.85) A/cm2.The results of the effect of this parameter on MRR are shown in table (1) The results show that material removal rate increases with increasing in current density.

NO. of exp.	Current Amper Value	Current Density (A/cm^2)	Gap Distance (mm)	Electrolyte concentration (g/l)	Tool Roughness (µm)	Particle Size (µm)	MRR (g/min)
1	30	11.93	1	200	1.07	82.432	0.5628
2	40	15.91	1	200	1.07	77.966	0.77031
3	50	19.89	1	200	1.07	64.062	0.9416
4	60	23.87	1	200	1.07	52.401	1.1365
5	70	27.85	1	200	1.07	24.618	1.3451
6	30	11.93	0.5	200	1.07	76.451	0.60381
7	30	11.93	0.75	200	1.07	78.967	0.58176
8	30	11.93	1	200	1.07	82.432	0.56286
9	30	11.93	1.25	200	1.07	87.391	0.5542
10	30	11.93	1.5	200	1.07	91.81	0.5436
11	40	15.91	1	100	1.07	89.218	0.74629
12	40	15.91	1	150	1.07	86.045	0.75657
13	40	15.91	1	200	1.07	77.966	0.77031
14	40	15.91	1	250	1.07	56.148	0.77757
15	40	15.91	1	300	1.07	32.406	0.7841

Table (1) cutting conditions

Faraday's law states that "The amount of mass dissolved (that removed by machining), is directly proportional to the amount of electricity which has flowed". The values of gap distance used for this experiments are (0.5, 0.75 , 1 ,1.25 ,1.5)mm .The results of effect of change in gap distance on the material removal rate are given in Tables (1). The result shows that the material removal rate decreases with increase in distance between workpiece and tool that causes increasing in Ohmic resistance of the electrolyte which reduces the amount of the current and decreases the amount of anodic dissolution. The values of electrolyte concentration used for this experiments were (100, 150, 200, 250, 300) g/l. The results of this parameter are shown in Tables (1). It is observed that increase in electrolyte concentration increases the MRR. With increasing the electrolyte concentration the electrical conductivity of the electrolyte increases and also that releases large number of ions in IEG, which results in higher machining current in the inter electrode gap (IEG) and causes higher MRR.

Prediction of particle size and metal removal

The statistical models based on the second-order polynomial equations were developed for particle size and MRR, the experimental results and are given below:

Prediction of Particle Size:

A prediction to particle size has been done by using second order polynomial response surface mathematical model in equation(1) ,the coefficients of the independent variables were obtained from the (RSM) model and applied in the equation

to be:-

$$Yu = 45.2338+3.85659X_1 +0.444438X_2 +0.381830X_3 - 0.185831 (X_1)^2+7.60618 (X_2)^2-0.00167218 (X_3)^2 \quad \text{.......... (3)}$$

where Yu in this equation is particle size, and the results of this response are shown in table(2). The values of R^2 and **adjusted** R^2 are 99.54% and 99.19%, this means that regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response (particle size).

Figure (1) displays the normal probability plot of the residuals for particle size, and It can be noted that the observed values and the regression model are well fitted. The results of the particle size from the regression model are given in Table (3) as predicted values (by the RSM) and the true values (from experiments), and the differences between the two values for the three cases are too small as shown in the Figurer (2) for more illustration.

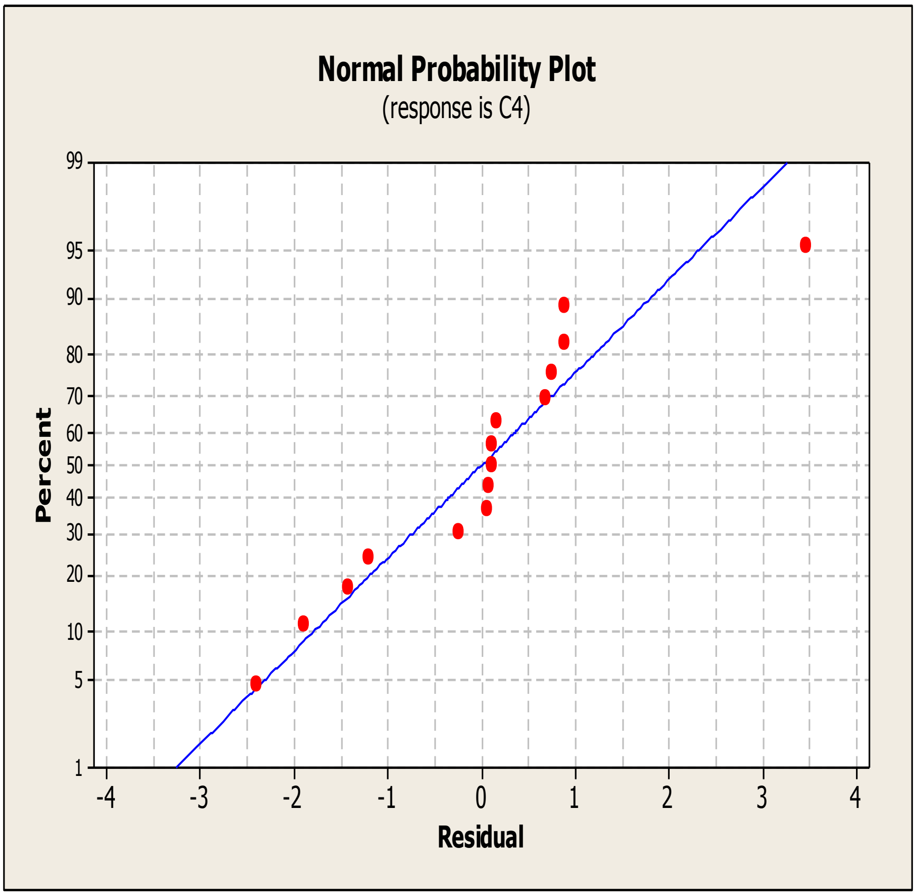

Figure (1) The normal probability of particle size.

Table (2) Coefficients of the independent variables for the particle size.

Independent variables	Coefficients(C)
Constant	45.2338
X_1	3.85659
X_2	0.444438
X_3	0.381830
$(X_1)^2$	- 0.185831
$(X_2)^2$	7.60618
$(X_3)^2$	-0.00167218

Table (3) Measured and predicted values of particle size.

NO. of exp.	Measured Particle size values(µm)	Predicted Particle size values(µm)	Residual Values
1	82.432	82.32389	0.10811
2	77.966	77.08243	0.88357
3	64.062	65.95369	-1.89169
4	52.401	48.93767	3.46333
5	24.618	26.03438	-1.41638
6	76.451	76.39703	0.05397
7	78.967	78.88507	0.08193
8	82.432	82.32389	0.10811
9	87.391	86.71347	0.67753
10	91.81	92.05383	-0.24383
11	89.218	89.06483	0.15317
12	86.045	87.25408	-1.20908
13	77.966	77.08243	0.88357
14	56.148	58.54988	-2.40188
15	32.406	31.65643	0.74957

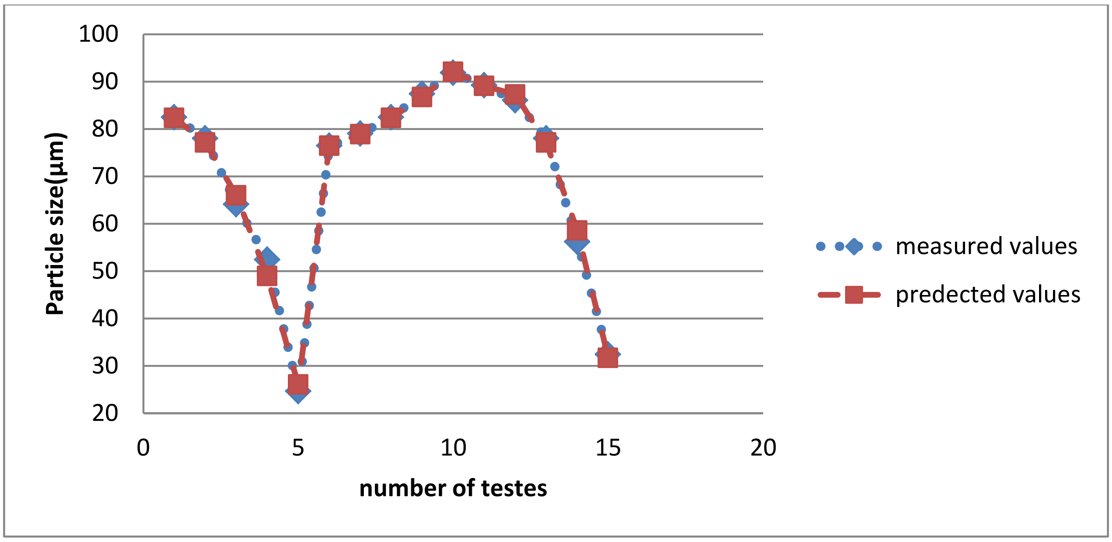

Figure (2) Relationship between measured and predicted values of Particle size

Prediction of MRR:

A prediction of MRR has been done by using second order polynomial response surface mathematical model in equation(1), the coefficients of the independent variables are obtained from the (RSM) model and applied in the equation to be:-

$$\boldsymbol{Yu} = 0.0513704+0.0489929\, \boldsymbol{X_1}-0.106465\boldsymbol{X_2}-2.75091*10^{-5}X_3-1.46909*10^{-5}\, (\boldsymbol{X_1})^2+0.0236367\, (\boldsymbol{X_2})^2+5.52573*10^{-7}\, (\boldsymbol{X_3})^2 \; \ldots\ldots\; \mathbf{(4)}$$

where Yu in this equation is MRR, and the results of this response are shown in table(4), the values of ***adjusted R***^{2} and ***R***^{2} are (99.87)% , (99.92)%,that's mean the regression model provides an excellent explanation of the relationship between the independent variables (Machining parameters) and the response of (MRR).

Figure (3) displays the normal probability plot of the residuals for MRR, it can be noted the observed values and regression model are totally fitted .The results of the Material Removal Rate from the regression model are given in Table (5) as predicted values (by the RSM) and the true values (from experiments), and the differences between the two values for the three cases are too small as shown in Figure (4) for more illustration.

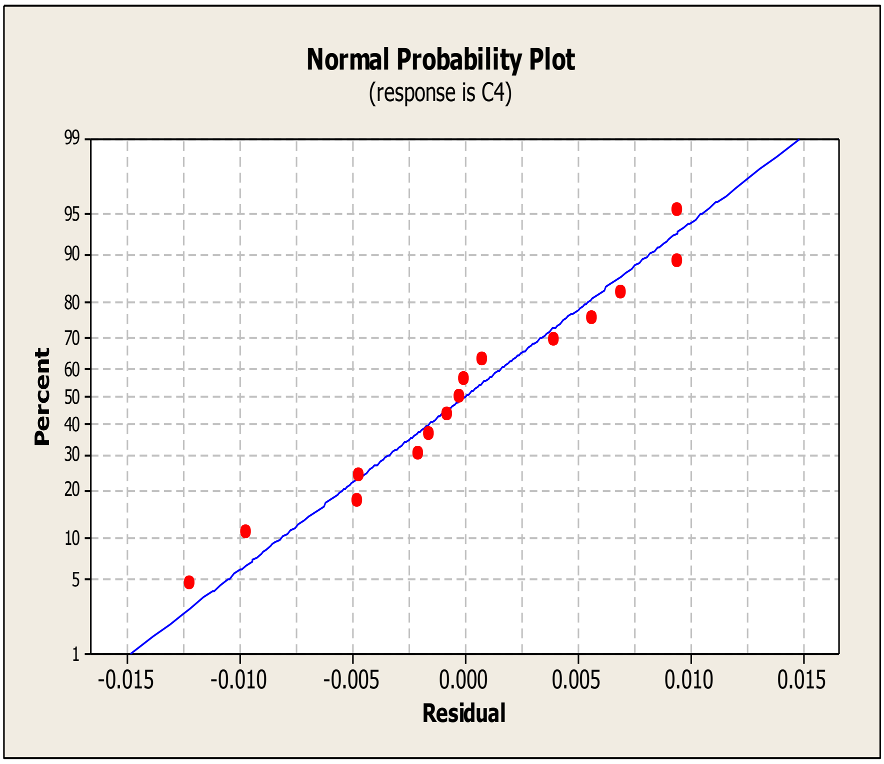

Figure (3) The normal probability of MRR.

Table (4)Coefficients of the independent variables for the MRR.

Independent variables	Coefficients**(C)**
Constant	0.0513704
X_1	0.0489929
X_2	-0.106465
X_3	$-2.75091*10^{-5}$
$(X_1)^2$	$-1.46909*10^{-5}$
$(X_2)^2$	0.0236367
$(X_3)^2$	$5.52573*10^{-7}$

Table (5) measured and predicted values of MRR

NO. of exp.	Measured mrr values(g/min)	Predicted mrr values(g/min)	Residual Values
1	0.5628	0.567537	$-4.737*10^{-3}$
2	0.77031	0.760901	$9.409*10^{-3}$
3	0.9416	0.9538	-0.0122
4	1.1365	1.146233	$-9.733*10^{-3}$
5	1.3451	1.3382	$6.9*10^{-3}$
6	0.60381	0.603042	$7.68*10^{-4}$
7	0.58176	0.583813	$-2.053*10^{-3}$
8	0.56286	0.567537	$-4.737*10^{-3}$
9	0.5542	0.554217	$-1.7*10^{-5}$
10	0.5436	0.54385	$-2.5*10^{-4}$
11	0.74629	0.747075	$-7.85*10^{-4}$
12	0.75657	0.752607	$3.963*10^{-3}$
13	0.77031	0.760901	$9.409*10^{-3}$
14	0.77757	0.771959	$5.611*10^{-3}$
15	0.78417	0.785779	$-1.609*10^{-3}$

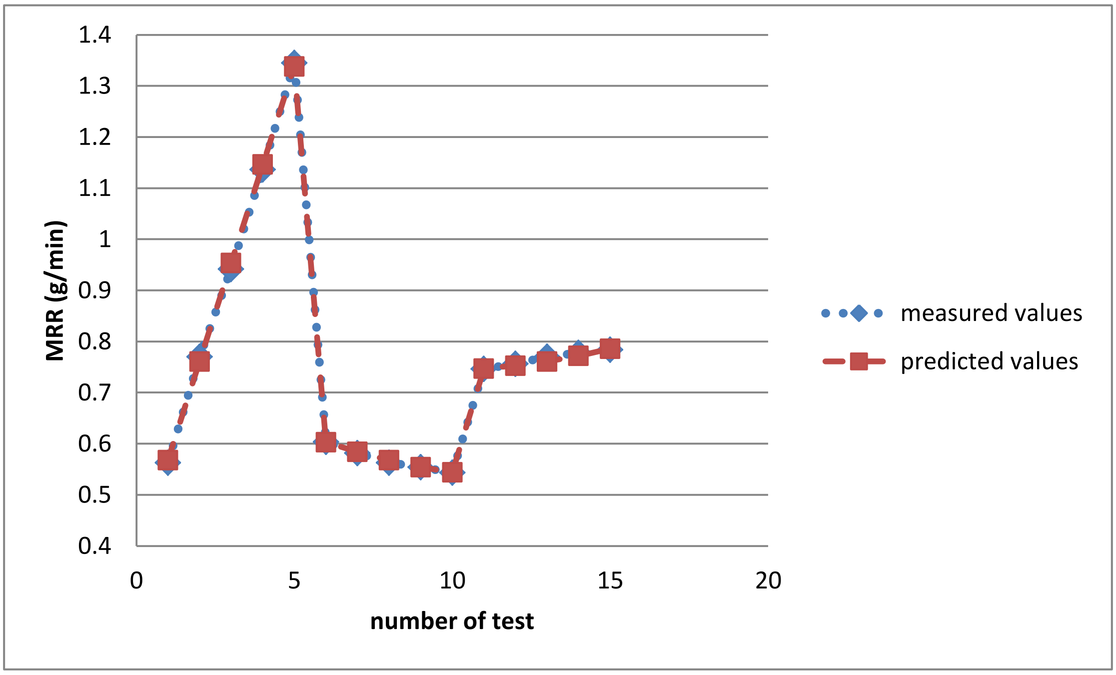

Figure (4) Relationship between measured and predicted values of MRR

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CONCLUSIONS

1- Electro chemical machining (ECM) is good method for reuse the waste in different application as zinc oxide.

2- Increasing in current density lead to decreases in particle size from (82.432µm to 24.618µm) and increasing in MRR by (58.15%).

3- it is observed that gap has great influence during ECM on surface roughness and metal removal rate.

4- (RSM) is used to predict the influence of (current density, gap distance and electrolyte concentration) on particle size and material removal rate (MRR). The results obtained when approximately equal to that of the experiments and the accuracy was (99.92%) for particle size and (99.54%) for MRR.

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