IJCPE
Iraqi Journal of Chemical and Petroleum Engineering

Iraqi Journal of Chemical and Petroleum Engineering
Vol.14 No.3 (September 2013) 33- 47
ISSN: 1997-4884

University of Baghdad
College of Engineering

Optimal Design of Cylinderical Ectrode Using Neural Network Modeling for Electrochemical Finishing

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Abstract

The finishing operation of the electrochemical finishing technology (ECF) for tube of steel was investigated In this study. Experimental procedures included qualitative and quantitative analyses for surface roughness and material removal. Qualitative analyses utilized finishing optimization of a specific specimen in various design and operating conditions; value of gap from 0.2 to 10mm, flow rate of electrolytes from 5 to 15liter/min, finishing time from 1 to 4min and the applied voltage from 6 to 12v, to find out the value of surface roughness and material removal at each electrochemical state. From the measured material removal for each process state was used to verify the relationship with finishing time of work piece. Electrochemical finishing proves an effective method to reduce the surface roughness ($R_{a)}$ from 1.6μm to 0.1μm in 4 min. Finally, the observed relationships were used to predicate the diameter of blank, tool diameter and flow rate by neural network modeling ANN which has inputs defined by the finished hole diameter, surface roughness, and finishing time. Three of hidden layers and their neurons were found by an integration procedure. The design charts observed from this study utilize the designers in predication of diameter for blank and design of electrode.

Keywords: Design; Electrode; Electrochemical; Polishing; Roughness

Introduction

Polishing is a tedious and necessary finishing operation for many products. The manual operations of grinding and polishing labor intensive and prompt for human error. The other mechanical polishing methods such as shot peening and sand blasting were rough and imprecise. The chemical etching-polishing methods were simple and cost effective. However, they are environmental safe. The finished surface may not meet surface quality requirements, Shuo-Jen Lee 2003. [1]

The applications of electrochemical machining technology have been established in specific industries and products. The ECM technology had been used in the production of spur gears of the automobile and the turbine blades of an aircraft.

Pa, 2010 studied a novel finishing tool was developed by using the two finishing processes of burnishing and electrochemical finishing. The finishing tool design included a burnishing tool and an electrode as a bore surface finish improvement, which goes beyond traditional boring by utilizing the continuous processes of burnishing and electrochemical finishing. Only a short time is required to make the bore surface smooth and bright with the use of these continuous

finishing processes. The experimental results show that the large current rating is closely concerned with the fast feed rate of the finishing tool and is advantageous to the finishing processes. A small end radius or a small thickness of the electrode provides a more sufficient discharge, which is advantageous for the finish. The finishing effect is better with a high rotational speed of the finishing tool, since the dregs discharge the electrochemical machining, and burnishing becomes easier, which is also advantageous to the finishing processes. The finishing timeusing continuous current was not as prolonged as with the pulsed current.

Ning Ma et al, 2010 [3] studied the anodic smoothing characteristics of PECF. They analyzed through a developed mathematical model. In their study, the main influencing factors such as the finishing time, the inter electrode gap, the applied voltage and the rotational speed of electrode have been examined. The predictive values based on the developed mathematical model are found to be in reasonable agreement with the experimental values. The surface roughness Rz ranges from 3µm to 1.22µm. The research achievement through various parametric studies can be used as a guideline for the operation of a PECF system.

Maksoud and Brooks, 1995 [4] reported grinding of ceramic form tooling with diamond powder and electrochemical technology. De Silva and McGeough 1989, conducted pulsed power supply of ECM technology for micromachining.

Choi and Kim, 1998 [6] employed electroplated CBN wheel for electrochemical deburring. The operating volt-age and current density of above ECM applications were generally high. The metal removal rate (machining) is important. It operates at the metallic dissolution of the electrochemical reaction. Those process parameters were too high for polishing purpose. Operating at lower range of voltage and current density, the electrochemical reaction exhibits passive characteristics.

The electrochemical polishing mechanisms of the electrochemical mechanical polishing were studied with linear polarization method and Faraday's law on the SKD11 tooling steel. The linear polarization method has been widely employed to characterize the electrochemical properties of a material after surface treatment.

Cai et al, 2003 [7] used I–V curves to characterize the changes in electrochemical and anti-corrosion properties after sand blasting and mechanical polishing of the titanium alloys.

Experimental Work

Fig. 1 shows the set-up of the electrochemical finishing system (ECF) for carrying out finishing operations on the inner surface of tube with diameter D.

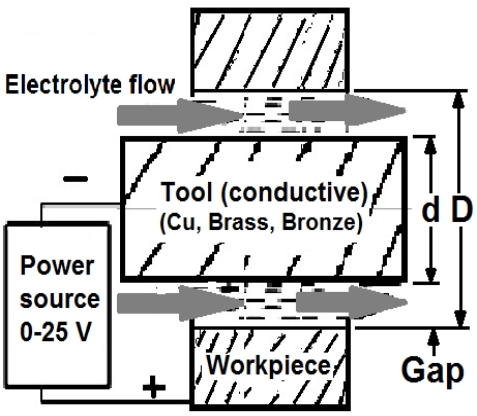

Fig. 1, The set-up of the electrochemical system

The work piece and the tool are being securely held by a three-jaw chuck and a clamp respectively, on convention machine type (SIG) as shown in Fig. 2. Both the work piece and the tool are insulated from the main body in order to only focus an

electrochemical reaction between the work piece and the tool. For using a fixed electrode in ECF, the working area of electrode is larger than the machined area, in the work piece.

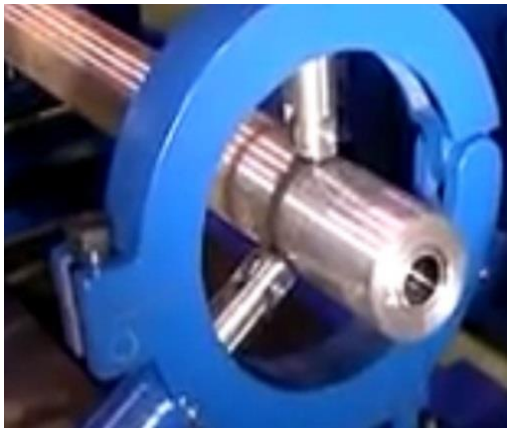

Fig. 2 The set-up of the work piece

Composition of work piece is given in Table (1). The raw material comes in the form of extruded bar with a diameter of 30 and 50mm. Before drilling, the bar was faced by turning.

Table 1, Composition of work piece

C (%)	Si (%)	Mn(%)	Cr (%)
0.86	0.40	0.45	0.05
Mo (%)	Co (%)	Fe	
4.5	4.0	Balance	

As given in Table (2) the samples for this study, were drilled with D_{blank} as shown in Fig. 3 in order to evaluate the influence of electrochemical finishing on surface, as material removal in mm^3 and surface roughness R_a in µm.

Experiments have been carried out on a developed ECF-setup to evaluate theinfluences of some process parameters on surface roughness and dimensions of holes.

In this study, three predominant machining parameters are involved. They are flow rate of electrolyte, machining voltage and finishing time.

Table 2, Groups of specimens

Dia. Of blank (mm)	Electrolyte Flow rate (lit/min)	Voltage (volt)			
5	5	6	8	10	12
	10	6	8	10	12
	15	6	8	10	12
10	5	6	8	10	12
	10	6	8	10	12
	15	6	8	10	12
15	5	6	8	10	12
	10	6	8	10	12
	15	6	8	10	12
Cells with gray color were predicated by ANN					

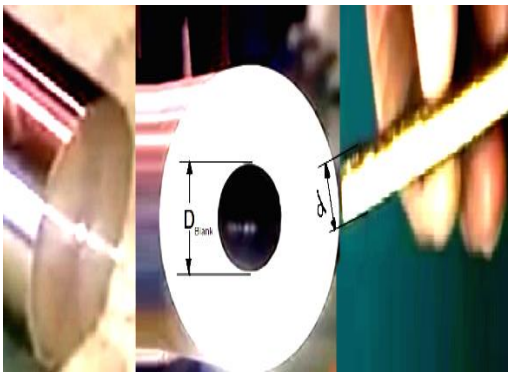

Fig. 3, The set-up of the blank and electrode

Results and Discussion

1. Surface roughness.

Fig. 4 to Fig. 12 shows the influences of the finishing time on the surface roughness (R_a) of holes, for different voltage. It can be observed form Fig.4 that the surface roughness (R_a) decreases with the finishing time and with applied voltage value at a particular parametric combination, i.e. diameter of blank, 5mm; flow rate of electrolyte, 5 l/min. Due to the increase in applied voltage, the machining current also increases. According to Faraday's law, the material removal rate is proportional to the machining current. However, Fig.4 obviously indicates that the surface roughness ($R_{a)}$ of machined hole was varied linearly. As shown in Fig.4, the R_a of hole from 6V decreases less rapidly than in the voltage of 8V. Fro 10V, the R_a decreases more rapidly than in the

voltage of 8V. Fro 12V, the R_a decreases more rapidly than in the voltage of 10V. With the increase of applied voltage, current density increases. These trends are the consequences of less increment of dissolution efficiency at low voltage range, i.e. between 6 to 12V.

By comparison, in the range of 6 to12V, the efficiency increment rate is more and the dissolution efficiency reaches towards its maximum value. Consequently, the R_a of finished-hole decreases with applied voltage. For example, when the applied voltage is 6V, the R_a can change from 1.6 to 0.1µm. When the applied voltage is 12V, the R_a can change from 1.6 to 0.05µm, with flow rate 5 l/min and finishing time 4 minutes for both cases. As shown in Figs. from 4 to 12.

As given in table (2) the samples for this study, were drilled with D_{blank} in order to evaluate the influence of electrochemical finishing on surface, as material removal in mm^3 and surface roughness R_a in µm. From a tool design standpoint, it is also of interest to be able to predict recommended operating conditions and the optimal toll diameter d, with future quantitates based on experimental data and requirement of finishing R_a, due predication by neural network modeling ANN.

Finishing of surface (R_a) is commonly described by parameters such as the centre-line-average or roughness average (CLA or 'Ra'), Ra is the universally recognized parameter of roughness. It is the arithmetical mean of the departures of the profile from the mean line, so that:

$$R_a = \frac{1}{L}\int_0^L |z|\,dx \qquad \ldots(1)$$

Where: L is the sampling length (m); z is the height of the profile along 'x' (m) as shown in Fig. 13.

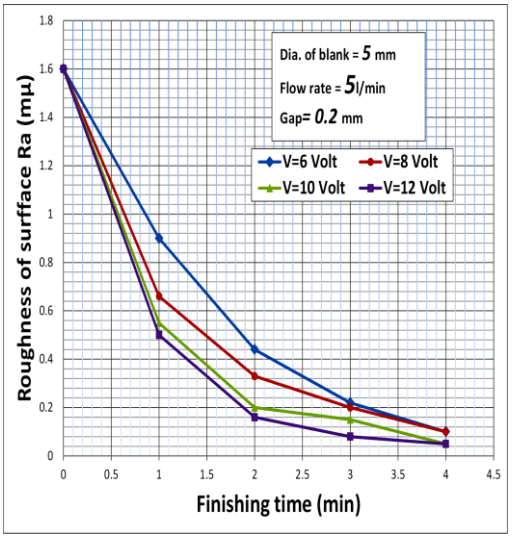

Fig. 4, The relation between finishing time and Ra for D_{Blank} 5mm with 5 liter/min flow rate

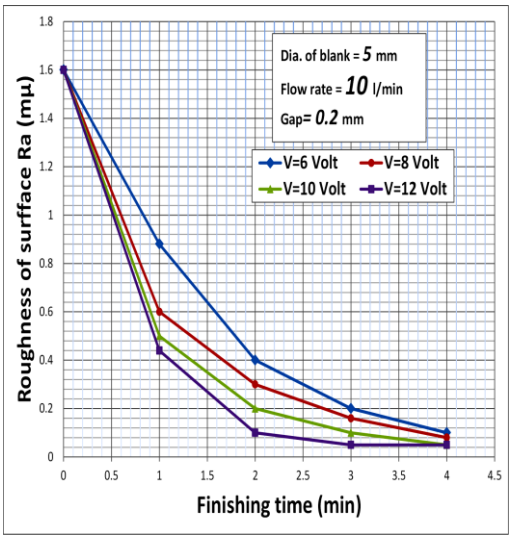

Fig. 5, The relation between finishing time and Ra for D_{Blank} 5mm with 10 liter/min flow rate

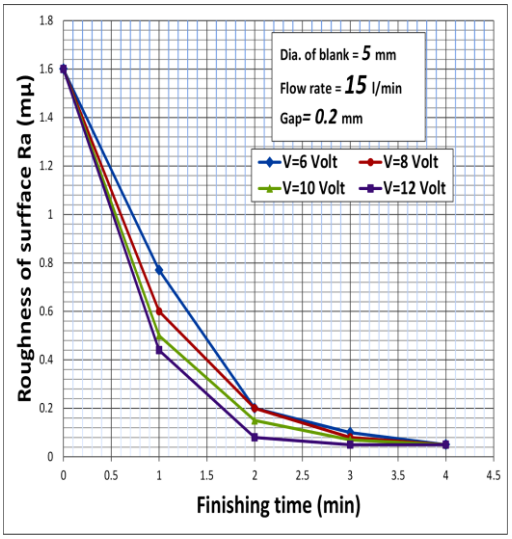

Fig. 6, The relation between finishing time and Ra for D_{Blank} 5mm with 15 liter/min flow rate

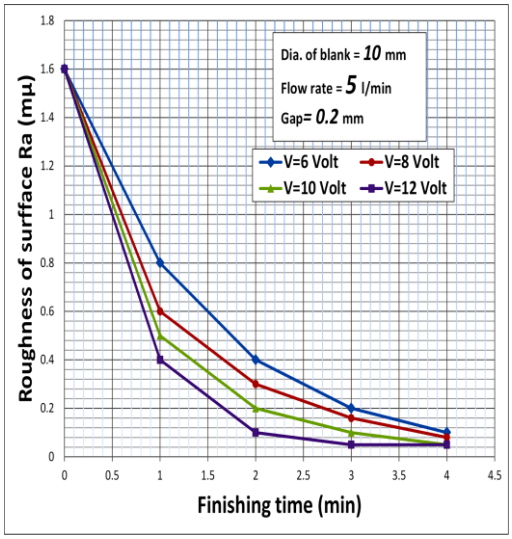

Fig. 7, The relation between finishing time and Ra for D_{Blank} 10mm with 5 liter/min flow rate

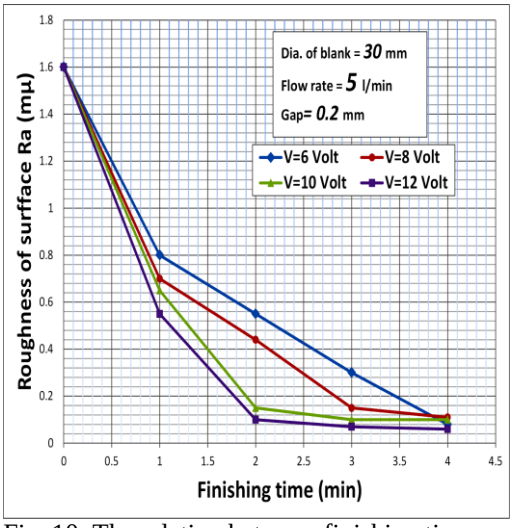

Fig. 10, The relation between finishing time and Ra for D_{Blank} 30mm with 5 liter/min flow rate

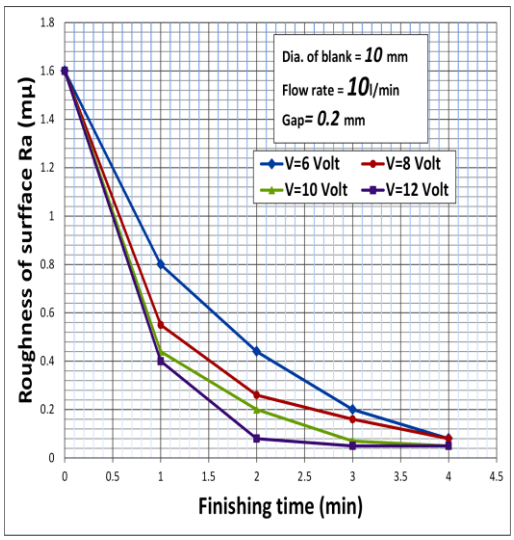

Fig. 8, The relation between finishing time and Ra for D_{Blank} 10mm with 10 l/min flow rate

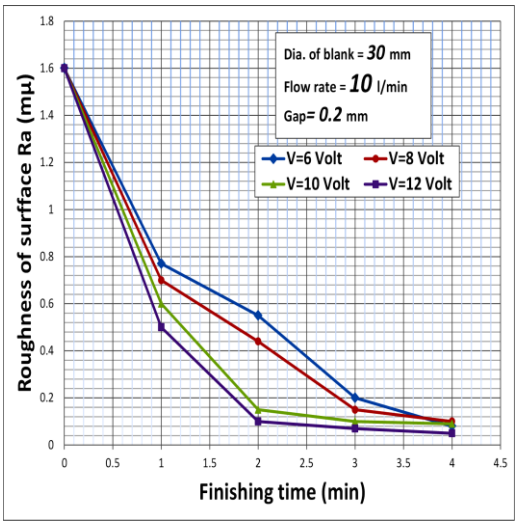

Fig. 11, The relation between finishing time and Ra for D_{Blank} 30mm with 10 l/min flow rate

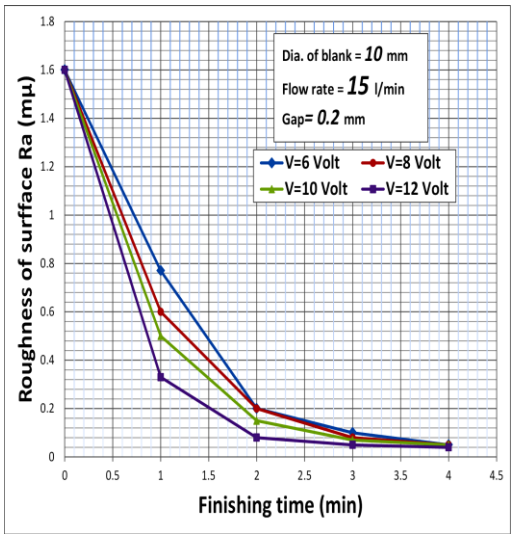

Fig. 9, The relation between finishing time and Ra for D_{Blank} 10mm with 15 liter/min

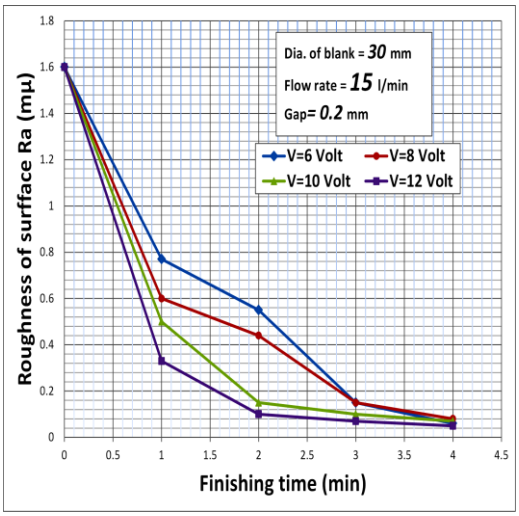

Fig. 12, The relation between finishing time and Ra for D_{Blank} 10mm with 15 l/min flow rate

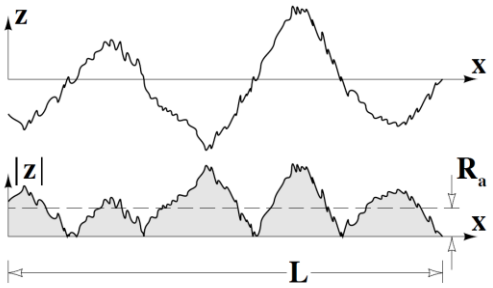

Fig. 13, The roughness average

The blank was drilled with hole larger than the diameter of electrode (d) as shown in Fig. 3, thus:

$D_{blank} = d + 2\ Gap$ ... (2)

Finished Dia. (D) = $D_{blank} + T$ … (3)

Where: Gap is the distance between surface of tool (electrode) and the inner surface blank, d is the diameter of electrode. T is the thickness of removal layer from inner surface, as:

$T = MR_{total} / \pi DL$ ... (4)

Where: L is the length of work piece.

The anode material dissolved electrochemically is flushed away by flowing electrolyte (typically NaCl and NaNO3 aqueous solution). With the continuous feeding of the tool, the shape produced in the work piece is nearly a negative mirror of the tool electrode, Zhiyong Li [9].

2. Material removal

Figs. from 14 to 22 show the effect of finishing time on the material removal value, for different of applied voltage at a particular machining condition, i.e. applied voltage machining voltage of 6V and flow rate of electrolyte, 5 l/min. The nature of curve is almost linear at one period, i.e. from 1 min to 2 min. The increment of material removal at high voltage case, i.e. from 6v to 12v, is more and so the material removal varies from 80 mm^3 to 110 mm^3, for 5mm diameter, at 5 l/min flow rate of electrolyte.

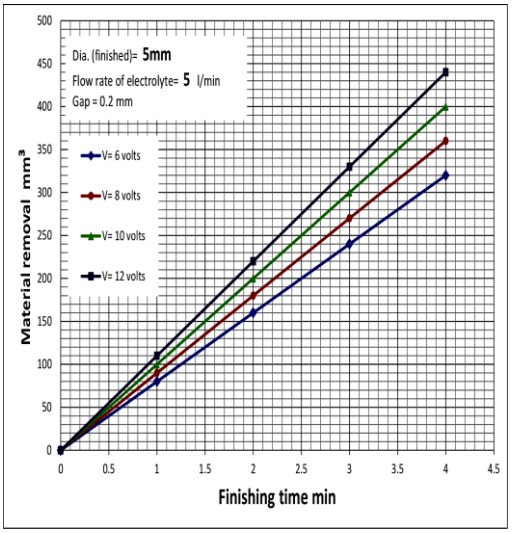

Fig. 14, The material removal with finishing time for D_{Blank} 5mm and Q=5 l/min

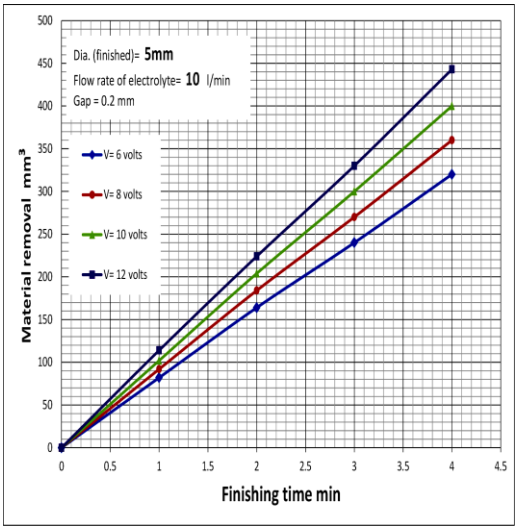

Fig. 15, The material removal with finishing time for D_{Blank} 5mm and Q=10 l/min

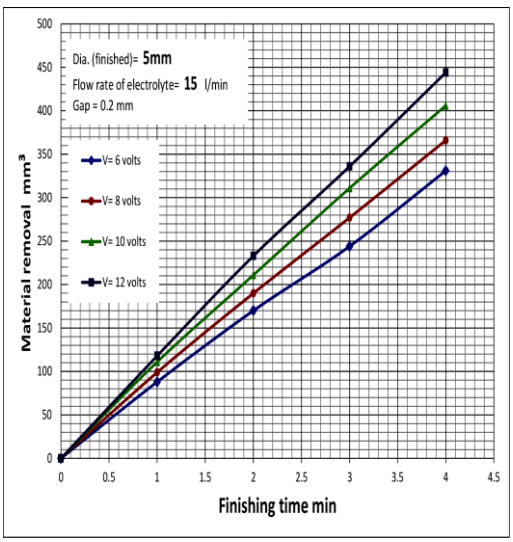

Fig. 16, The material removal with finishing time for D_{Blank} 5mm and Q=15 l/min

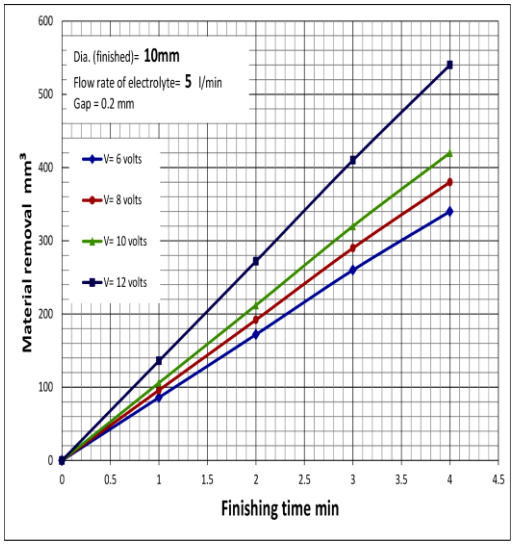

Fig. 17, The material removal with finishing time for D_{Blank} 10mm and Q=5 l/min

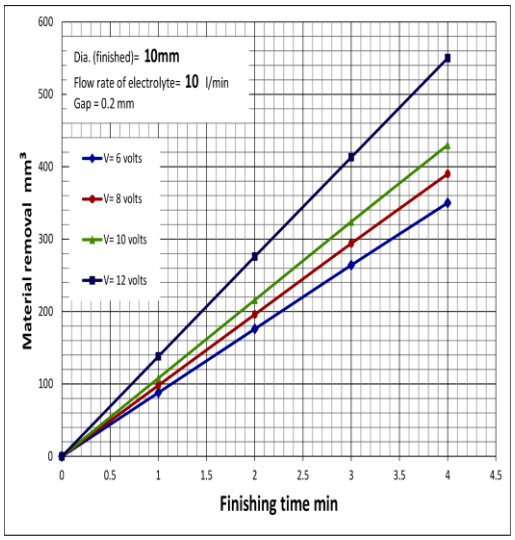

Fig. 18, The material removal with finishing time for D_{Blank} 10mm and Q=10 l/min

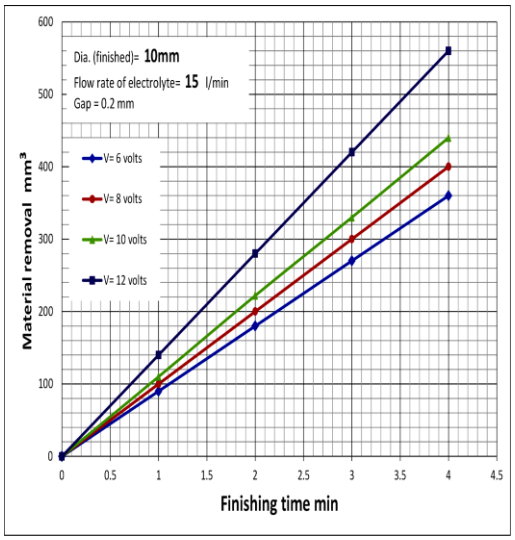

Fig. 19, The material removal with finishing time for D_{Blank} 10mm and Q=15 l/min

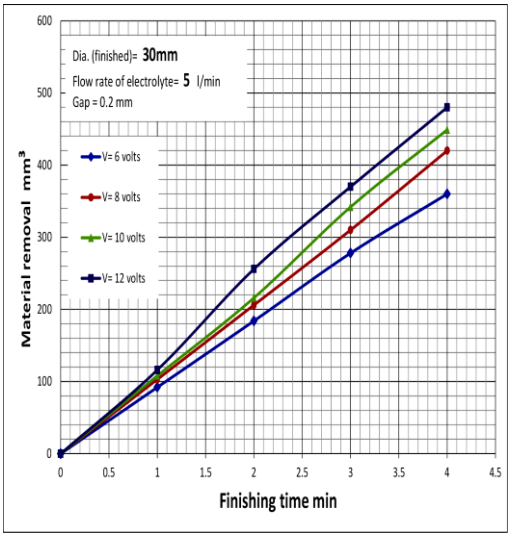

Fig. 20, The material removal with finishing time for D_{Blank} 30mm and Q=5 l/min

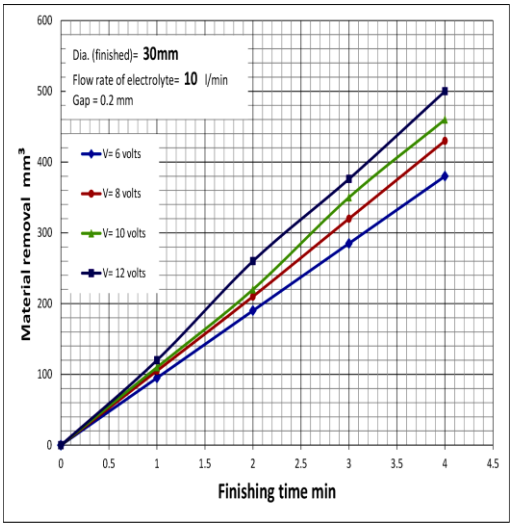

Fig. 21, The material removal with finishing time for D_{Blank} 30mm and Q=10 l/min

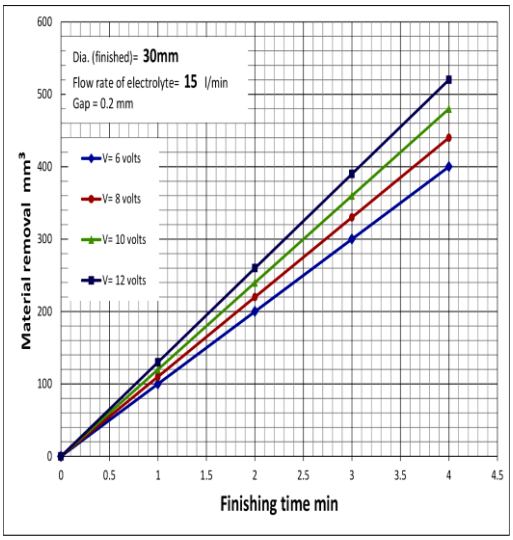

Fig. 22, The material removal with finishing time for D_{Blank} 30mm and Q=15 l/min

In high applied voltage, the large number of ions associated in the machining process increases the machining current density and thus results in the larger diameter of hole. Furthermore, the experimental results also demonstrate that material removal. The diameter of machined holes with different flow rate of electrolyte is shown in Figs. from 14 to 22. It is clear from figures that the increasing for value of removal material, with the inccrease of the applied flow rate of electrolyte increase.

Material removal rate (MRR) is an important characteristic to evaluate efficiency of a non-traditional machining process. In ECM, material removal takes place due to atomic dissolution of work material. Electrochemical dissolution is governed by Faraday's laws. The first law states that the amount of electrochemical dissolution or deposition is proportional to amount of charge passed through the electrochemical cell, which may be expressed as:

$$M \propto Q \quad \ldots(5)$$

Where: m = mass of material dissolved or deposited, Q = amount of charge passed.

The second law states that the amount of material deposited or dissolved further depends on Electrochemical Equivalence (ECE) of the material that is again the ratio atomic weigh and valiancy. Thus

$$m \alpha ECE \alpha A/v \quad \ldots(6)$$

Where: ECE= Electrochemical Equivalence, A=the atomic weights, v= valiancy, Thus:

$$m \alpha (QA)/v \quad \ldots(7)$$

$$m= ItA/(Fv) \quad ...(8)$$

Where: F= Faraday's constant =96500 coulombs, I= current, t= time.

$$MRR= m/(\rho t)= IA/(F\rho v) \quad \ldots(9)$$

Where MRR = Material removal rate, ρ= density of the material.

The engineering materials are quite often alloys rather than element consisting of different elements in a given proportion.

Let us assume there are 'n' elements in an alloy. The atomic weights are given as A1, A2, An with valiancy during electrochemical dissolution as ν1, ν2 ,.., νn. The weight percentages of different elements are α1, α2, αn (in decimal fraction)

Now for passing a current of I for a time t, the mass of material dissolved for any element 'i' is given by:

$$Mi = \Gamma a \ \rho \ \alpha i \quad \ldots(10)$$

Where Γa is the total volume of alloy dissolved. Each element present in the alloy takes a certain amount of charge to dissolve

$$mi=QiAi/(F\nu i) \quad \ldots(11)$$

$$Qi= Fmi\nu i/ Ai \quad \ldots(12)$$

$$Qi= F \ \Gamma a \ \rho \ \alpha i \ \nu i/ Ai \quad \ldots(13)$$

The total charge passed= ΣQi

$$Q_T=I \ t \quad \ldots(14)$$

$$QT= F \ \Gamma a \ \rho \ \Sigma \ \alpha i \ \nu i/ Ai \quad \ldots(15)$$

Now:

$$MRR= \Gamma_a/t \quad \ldots(16)$$

$$MRR = \frac{\Gamma_a}{t} = \frac{1}{F\rho} \cdot \frac{I}{\sum \frac{\alpha_i \nu_i}{A_i}} \quad \ldots(17)$$

The material removal from surface produced a new surface with smoothness, as shown in Fig. 23.

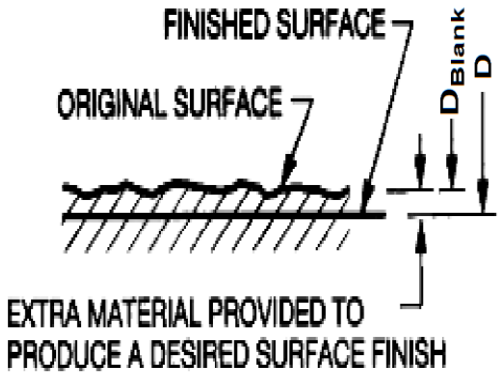

Fig. 23, The relation between finished and original surfaces

Air bubbles also sometimes accompany the electrolyte due to the improper control of electrolyte flow and other gas bubbles like H2 are generated during the electrochemical process. Zhiyong Li [10].

Fig. 24 shows a sample of the relationship between the gap value and material removal. The gap affect on material removal was studied with same manner, for gap 0.2, 0.4, 0.6 and 1.0mm. A sample of these results.

Due to Fig. 23, which is show the surface topography of workpiece before and after ECF. It can be found that the surface topography finished by ECF is much different from original mechanically machined surface profile. As shown in Fig. 23, wave crests of original mechanically machined surface profile disappear quickly after ECF. This is mainly due to the concentration of current lines on wave crests of a surface profile thus leading to a locally higher dissolution rate Landlot [11] and other researcher [12-18], which is popularly considered.

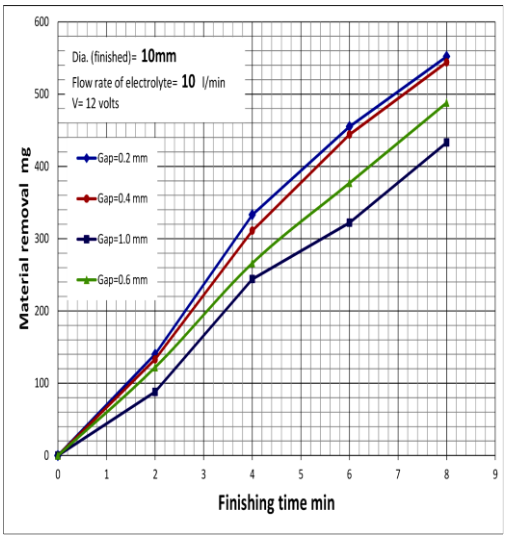

Fig. 24, A sample of the relation between finishing time and material removal for Dia.10mm

3. Optimal design by ANN.

The previous results in this study were used in order to evaluate the technical requirement; recommended operating conditions, diameter of the blank D_{blank} , diameter of the electrode. The recommended operating conditions; applied voltage, electrolyte flow rate (liter/min) and the gap.

The influence of electrochemical finishing on surface; material removal in mm^3 and surface roughness R_a in µm. These experimental data were used as input data, for ANN programming, with operating conditions for each state.

From a tool design standpoint, it is also of interest to be able to predict the recommended operating conditions, for the required finished surface roughness. The first stage of the ANN resultants is the fixing of the recommended operating conditions for required finished surface roughness. Secondly, the thickness of material removal was estimate, to predicate the tool diameter d, due to the technical recommendation and design requirements, based on experimental data, with predication by neural network modelling ANN.

The input-output mapping of a multi-layer perceptron is established according to requirements of this study, Fig. 25 show the block-diagram for modeling and program, consist of inputs which are defined by finished hole diameter (D), surface roughness (Ra), and finishing time (t). Network outputs were defined by diameter of blank (D_{Blank}), tool diameter (d), and flow rate (Q). Data sets was clustered and grouped as a combination based on other variables (e.g. gap, applied voltage,…etc).

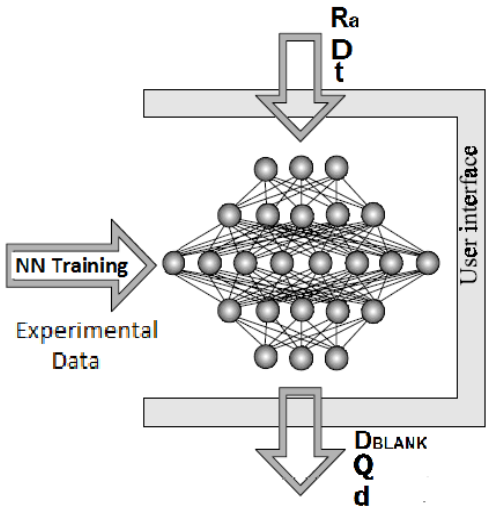

Fig. 25, Multi-layers; input, output and hidden

Initially, the number of neurons in hidden layer was found by an iteration procedure, in which 3 hidden layers was assumed, each consist of 50 neurons. Training procedure was performed and the resulting performance index was saved. Then, the number of neurons was reduced by one. Training procedure was performed again and the resulting performance index was compared with the previous one. This procedure was repeated until minimum performance index was found. In this study, neural networks have three hidden layers with the number of neurons being approximately between 5 and 27 and at most two hidden layers with 8 fixed neurons in the second layer and the number of neurons in the third layer being between 5 and 10. MATLAB neural network toolbox was used to create and train networks as shown in appendix A. Fig. 26 show the ordinary operations of classic design before ANN. The observed data from experiment work was used for training of ANN. Table (3) show the structures and performances of Neural Networks.

Table 3, Performances of Neural Networks

Training algorithm	No. training epochs	Mean squared error MSE	*R* correlation coefficient
Gradient descent method	88	2.961314 e-002	0.99854

Figs. 27 to 33 show samples of the ANN resultants, as design charts. The operating conditions and required finished surface roughness should be estimated, firstly, in tool design process. Secondly, use these design charts, to estimate the tool diameter d and diameter of blank, due to these charts.

The new data, in this study, was predicated by using neural network method. The predication based on previous works of other many researchers; Hu¨sken et al 2005 [20], studied the structure optimization of neural networks for evolutionary design optimization. They studied the use of neural networks as approximate models for the fitness evaluation in evolutionary design optimization.

Xiaoyu, 2008 [21], estimated the tool wear modeling in hard turning by using neural network. The estimation was based on a fully forward connected neural network with cutting conditions and machining time as the inputs and tool flank wear as the output.

Paulo R. Aguiar et al 2008 [22], they used the grinding parameters as input to the neural network, which have not been tested yet in surface roughness

prediction by neural networks. Besides, a high sampling rate data acquisition system was employed to acquire the acoustic emission and cutting power.

Qing-hua Yang et al 2012 [23], studied the optimum design of combined cold extrusion die for bevel gear by using neural network. Neural network is used to establish mapping relationship between die and process parameters and maximum extrusion force.

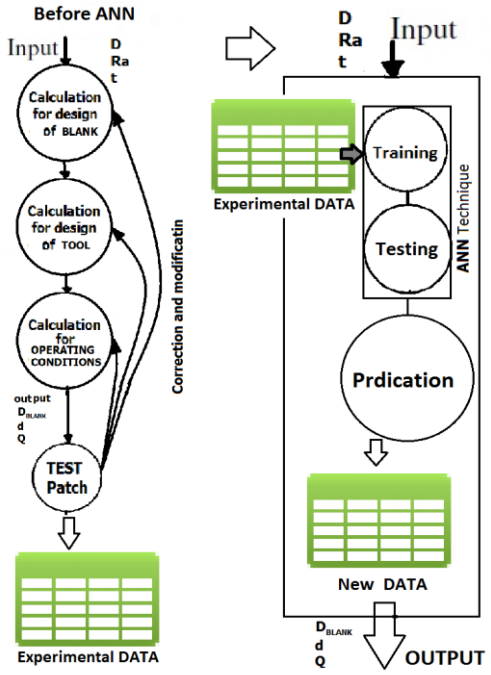

Fig. 26, The design operations before and after ANN

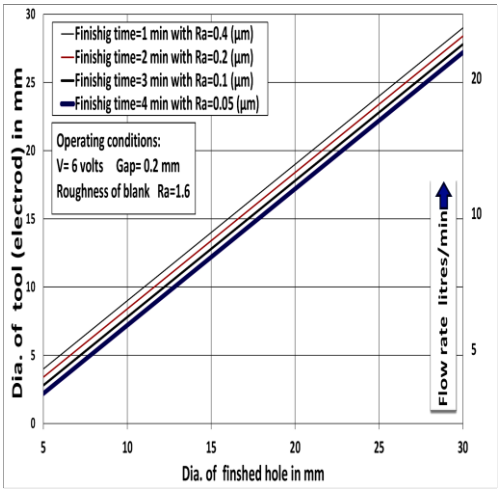

Fig. 27, Design chart of electrode at applied voltage 6v and gap 0.2mm

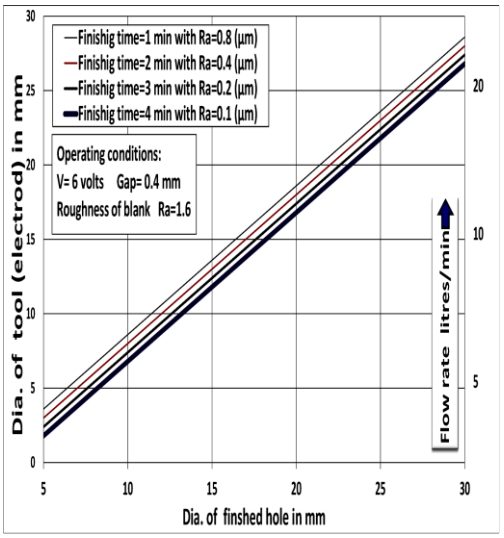

Fig. 28, Design chart of electrode at applied voltage 6v and gap 0.4mm

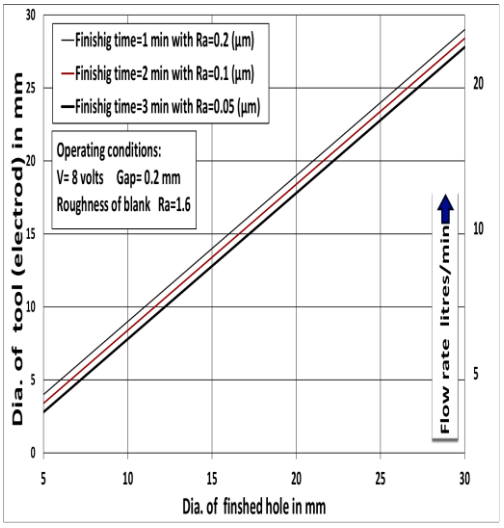

Fig. 29, Design chart of electrode at applied voltage 8v and gap 0.2mm

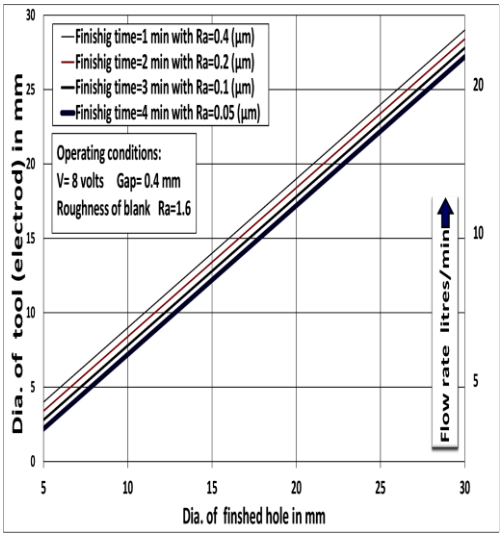

Fig. 30, Design chart of electrode at applied voltage 8v and gap 0.4mm

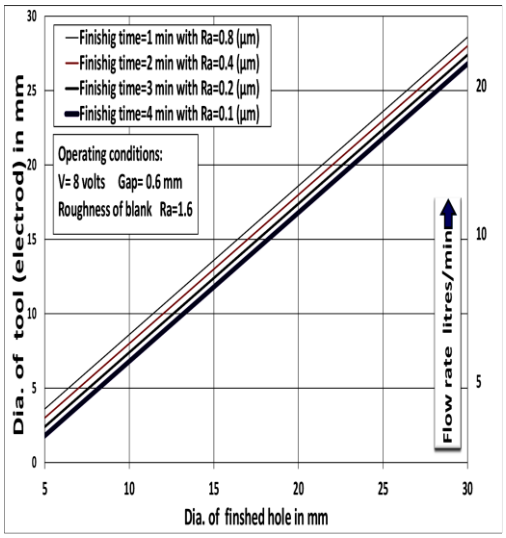

Fig. 31, Design chart of electrode at applied voltage 8v and gap 0.6mm

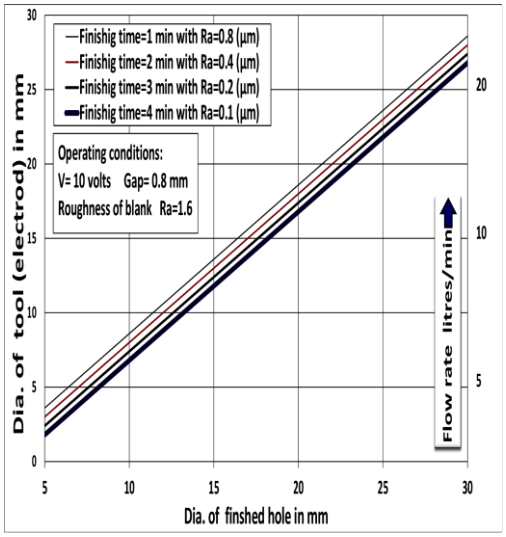

Fig. 32, Design chart of electrode at applied voltage 10v and gap 0.8mm

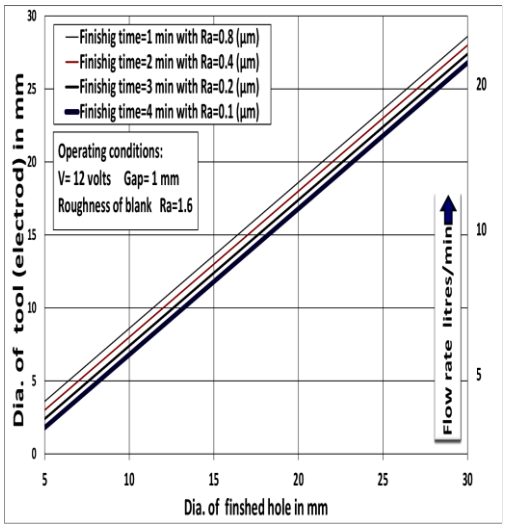

Fig. 33, Design chart of electrode at applied voltage 12v and gap 1.0mm

Fig. 34 shows final design chart, due to optimization of Figs. From 27 to 33, by ANN modeling based on the technical recommendation (applied voltage, value of gap and flow rate of electrolyte) and design requirements (finished diameter D and Ra of finished surface), based on experimental data, with extended range, using predication by neural network modeling ANN.

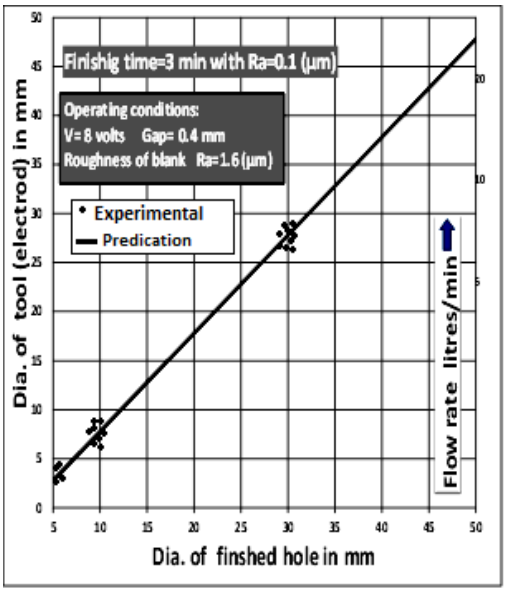

Fig. 34, Design chart of electrode at recommended conditions

In comparing the results of this study with those of reference [1, 17], the operating condition and finishing requirement were considered respectively. And in comparing the numerical results of ANN modeling of predication for D_{Blank} and Dia of tool (d), that are obtained from ANN technique.

Conclusions

In the present work, an idealized design of electrode, for mass production has been developed and verified experiments have been performed with different finishing parameters. Some key findings the experimental investigation are listed as follows:

1) Electrochemical finishing (ECF) proves an effective method to reduce the surface roughness R_a from 1.6µm to 0.1µm in 4 min.
2) In order to reduce several microns of the maximum height of the profile, it needs to remove a few hundred of microns from the workpiece surface. For example, the total removal thickness is equal to 300µm in order to reduce the R_a from 1.6µm to 0.1µm in 4 min.
3) For good surface quality, it was suggested to operate at applied voltage 12v and flow rate of electrolyte of 15 liter.
4) It is easily implemented as a generalized system of design for tool, based on neural network, system has an open structure which enables improvements and further revisions of knowledge bases.
5) A collaborative optimization method for the design of electrochemical polishing requirement is presented in this paper, combined using design knowledge (know-how), experimental data and the predication and optimization capability of neural network.

Nomenclature

ECF: Electrochemical finishing.
ECM: Electrochemical machining.
PECF: Pulse electrochemical finishing.
ANN: Artificial neural network.
MRR: Material removal rate (mm^3//min).
MRR: Material removal (mm^3).
D_{Blank}: Diameter of blank.
d : Diameter of tool.
D : Diameter of finished hole.
Ra : Surface roughness.
SKD11: Tooling steel with high chrome.
R : Correlation coefficient.
MSE : Mean squared error.

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Appendix A:

Neural Networks Program

```
DataFileName='nad1';
OP_File_Name=[DataFileName
'_Results'];
Data=xlsread(DataFileName);
[ROW,COLOM]=size(data);
Ra=data(2:ROW,1)';
t= data (1,2:COLOM)';
D= data (2:ROW,2:COLOM)';
Q=data(2:ROW,1);
Db= data (1,2:COLOM);
d= data (2:ROW,2:COLOM);
IP=[];Target=[];
```

```
IP=[Ra;t;D];
Target=[Q,Dp,d];
PR=[min(Ra) max(Ra);min(t) max(t)
);min(D) max(D)];
LayerSize=[No_Of_Neurons];
net = newff(PR,LayerSize,{'tansig'
'purelin'});
net = train(net,IP,Target);
Y = sim(net,IP);
ddd=xlswrite(nadhum1.xls,Y)
```