Effect of Current on Average Surface Roughness of Borosilicate Glass at EDM Machining and Comparison with Numerical Programs

Dr. Wathik I. Mahdi[*] , Dr. Maan A. Tawfiq[**] & Dr. Shukry H. Aghdeab*

Received on:6/5/2008
Accepted on:31/12/2008

Abstract

Machining of electrically non-conducting materials like glass is still a major problem. The principle of electric arc was used to generate high electrical discharge (spark) at high currents to machine non-conducting materials at any hardness, which is a new approach.

EDM system was build for machining of non-conducting cutting materials such as glass with new technology including the use of powder (graphite) mixed for dielectric solution (tap water) by supplied AC current values (200, 250, 300, 350 and 400A). Voltage of (70V) was used to cut 3mm thickness of borosilicate glass (BSG) to obtain the average surface roughness (Ra) of about (0.003-0.012µm) but the Ra before the machining was (0.005-0.006µm).

Numerical program called "Simulent" has been used to investigate the process control for EDM by using GN, BPN, PN and VQN that could predict the Ra with accuracies of 94.236, 94.034, 96.628 and 92.875% respectively from training data sets.

The differences on the Ra at different network models for 3mm thickness of BSG never exceed (8%) from testing data sets while the comparison of numerical results with experimental results of Ra among the measured values and prediction various network models, shows a differences between (1-8%).

The best predication accuracy is by the use of PN than other network models.

Keywords: Surface Roughness, EDM, MRR, REW.

تاثير التيار المستخدم في عمليات القطع بالشرارة الكهربائية على الخشونة السطحية لزجاج البوروسيليكات ومقارنتها مع نتائج تحليلية

الخلاصة

قطع المواد غير الموصلة كهربائيا مثل الزجاج مازال مشكلة رئيسية 0مبدا القوس الكهربائي تم استخدامه لتوليد شرارات كهربائية عالية عند تيارات عالية وبوجود مسحوق الكرافيت المضاف للماءالصافي واستخدام التيار المتناوب لقطع المواد غير الموصلة عند اية صلادة وهي طريقة جديدة

تم بناء منظومة شرارة كهربائية لقطع مواد غير موصلة مثل الزجاج مع تقنية جديدة متضمنة استخدام مسحوق الكرافيت ممزوج مع الماء الصافي بتسليط تيار متناوب0تم استخدام فولتية(70V) وقيم تيار متناوب تتراوح بين (200-400A) لقطع سمك (3mm) للحصول على متوسط خشونة سطحية صغير جدا حوالي (0.003-0.012µm) لكن الخشونة السطحية قبل التشغيل كانت (0.005-00.006µm) استخدمة برنامج رقمي يسمى(Simulent) للسيطرة على عملية القطع بالشرارة الكهربائية باستخدام(GN, BPN, PN and VQN) متمثل بالتنبوء بمعدل الخشونة السطحية(Ra)

* Control and Systems Engineering Department, University of Technology/ Baghdad
** Production Engineering and Metallurgy Deptartment, University of Technology/ Baghdad

وبدقة تتراوح (94.236, 94.034, 96.628 and 92.875%) على التوالي من مجموعـــة بيانـــات التدريب.

الفرق لمعدل الخشونة الـسطحية عنـد نمـاذج لـشبكة مختلفـة ولـسمك (3mm) لزجـاج البوروسيليكات لايتجاوز عن (8%) من مجموعة بيانات الاختبار0مقارنة النتائج الرقمية مع النتـائج التجريبية بين ان معدل الخشونة السطحية بين القيم المقاسة والتنبؤات لمختلف موديلات الشبكة وكان الفرق بين .(1-8%)

افضل دقة متوقعة باستخدام (PN) عن موديلات الشبكة الاخرى بسبب ان الـشبكة المـذكورة تستخدم مسار رياضي مفرد وموسع اقل من موديلات الشبكات الاخرى0

1- Introduction

Electrical Discharge Machining (EDM) is a thermal erosion process in which an electrically generated spark vaporizes electrically conductive material as shown in Fig. (1) [1].

EDM is one of the most extensively used non-conventional material removal processes [2]. Both electrode (tool) and workpiece must be electrically conductive [3]. The spark occurs in a gap filled with dielectric solution between the tool and workpiece. The process removes metal via electrical and thermal energy, having no mechanical contact with the workpiece [4]. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage in the manufacture of mould, die, automotive, aerospace and other applications. In addition, EDM does not make direct contact between the electrode and the workpiece eliminating mechanical stresses, chatter and vibration problems during machining [2].

Chen and Mahdavian (1999) [5] studied the different values of discharge current, pulse duration time and interval time in EDM to effects on the material removal rate, surface quality and dimensional accuracy of the tool and product.

Deng and Lee (2000) [6] studied the surface integrity of electro-discharge machining processes, ultrasonic machined, and diamond saw cut ceramic composites. They concluded that the surface roughness is between (1.64-2.55µm) at voltage (55V) and current range (5-14 A).

Jain et al. (2002)[7] studied the Machining of electrically non-conducting materials like alumina and glass by use electrochemical spark abrasive drilling (ECSAD) experiments have been conducted using abrasive cutting tool compared to a conventional cutting tool. They concluded that the machining performance of the ECSAD process using abrasive cutting tools keeps improving with an increase in supply voltage (50-70V), and cause increase in temperature of the electrolyte (55-70°C).

Puertas et al. (2004) [8] studied the analysis (modeling procedures) of the influence of EDM parameters on surface quality, MRR and EW of conductive ceramics (WC-CO). They concluded that the show the estimated response surface for the Ra parameter, electrode wear and MRR according to the design parameters of intensity and pulse time.

Wuthrich and Fascio (2005) [9] studied the machining with electro-chemical discharges able to machine several electrically non-conductive materials like glass or some ceramics. This technology remains an academic application and was never applied in industrial context. It was concluded that a large class of materials (glass, quartz, various ceramics and others) can be machined. Material removal rates depend on a large number of parameters like material to be machined, electrolyte, applied voltage and temperature.

Puertas et al. (2005) [10] studied the surface roughness on the die-sinking electrical discharge machining (EDM) of silicones. They showed their work increasing current (3-5A) and voltage (120-200V) increase S_m (response surface) from 59-119µm.

Tsuneo and Mitsuro (2006) [11] studied the EDM and ECM complex machining technology. First, EDM shaping and ECM finishing technology are investigated. These processes are carried out in sequence on the same machine tool with the same electrode (copper) and the same machining liquid (water). They concluded that the EDM surface roughness of 1µm Ra is improved to 0.2µm Ra by applying ECM.

2- Surface Integrity

The surface produced by the EDM process consists of a multitude of small craters randomly distributed all over the machined face [12]. These craters depend on the physical and the mechanical properties of the material and the composition of the machining medium as well as on the discharge energy and duration as shown in Figs. (2) and (3) [13]. The quality of surface mainly depends up on the energy per spark. If the energy content is high, deeper craters will result, leading to a poor surface [12]. Because the crater size depends on spark energy, and spark energy varies widely, the EDM surface finish has a range from 0.2 to 12.5µm Ra [3]. The integral effect of many thousands of discharges per second leads to the formation of the corresponding workpiece profile with a specified accuracy and surface finish. The depth of the resulting craters usually represents the peak to maximum surface roughness. The maximum depth of the damaged layer can be taken as 2.5 times the average surface roughness (Ra). The average roughness can be expressed in terms of pulse current I_p (A) and pulse time t_p (µs) by [13]:

$$Ra = 0.0225\, I_p^{0.29}\, t_p^{0.38} \qquad \text{........... (1)}$$

The desired end result of EDM is to produce a finished product with specified dimension, and a certain surface finish [4]. Surface roughness increases linearly with an increase in the material removal rate [13].

3- Experimental Conditions

Experiments were done on EDM machine attached with a dielectric solution. Graphite powder was mixed with tap water in a certain proportion (40g/L). The essential machining parameters for EDM were listed in table (1), which are typical sequence of machining regimes used for the finishing phase of a non-conventional EDM second electrode operation.

The electrode penetration through the workpiece is kept by orbital movement of a speed (22rpm), connected to the negative polarity was used.

The practical implementation of EDM is shown in Fig. (4), the BSG to be machined is dipped in to an appropriate dielectric solution (typically tap water and graphite powder). A pulsed voltage (AC) is applied between the machining-tool or tool-electrode (cathode) and the plate-electrode (anode).

The tool-electrode is dipped to a few millimeters into the dielectric. The plate-electrode is supported between workpiece (glass) and tool-electrode (steel).

EDM depends on the voltage and current for workpiece machining. Typical voltage values are around 70V (constant). High current values are around (200-400A). At this point, the density of gas bubble produced is so high that they coalesce into a gas film isolating the tool electrode from the dielectric. The electrical field in this film is high enough to allow electrical sparks between the tool electrode and the dielectric. This spark is generated in the space between the tool-electrode and workpiece. The spark creates a small difference between gap distances; therefore a localized location is less likely to be subjected to a spark until the sites around this point have been machined to the same level.

The spark creates a temperature high enough to melt the workpiece and create a chip which is then carried a way from the work area by the dielectric solution.

3-1 Machine and Power Supply

The experimental work has been performed on milling machine model (Bridgeport 3D Vertical), located at the machine tool laboratory.

It has the following specification:

1- Spindle speed (22- 3750rpm) having 15 speed steps.
2- Motor power (1.5Kw) and 380V (50-60Hz).

The unit used of AC 380V input voltage contains of (three phase), and output voltage 70V (two phase), but are available with other currents like 200-400A. A generator for the experimental work unit used is available in welding machine (50/60HZ) type MMA 4040/ T-cell (Cebora-Italian). Generators currents range is (10-400A) depending on how industrial application.

3-2 Workpiece

The workpiece used are made of borosilicate glass (BSG), non-conducting material at 3mm thickness. During experiments, BSG are taken as work material. Properties of the material are given in Table (2).

3-3 Electrodes

Two types of electrodes are used in the experimental work:

3-3-1 Tool-Electrode

In the present work the cutting tool was selected as a conical shape (tip end) in order to machining of BSG. The electrode material selected as AISI 1045 tool steel with diameter of 6mm were used in this experiment and their chemical composition and mechanical properties are given in Tables (3) and (4), because of its electrical conducting, property it can carry high temperature, maintain a good tool-to-workpiece wear ratio, and high resistance with 90mm in length, and connected to the negative polarity.

3-3-2 Plate-Electrode

In this developed system, a high spark current AC power supply voltage is supplied between the steel tool cathode (tool-electrode) and the anodic plate graphite electrode, which is placed in a dielectric solution (tap water and graphite powder). The plate-electrode material is a high purity for carbon with (100*70*15mm) dimensions and connected to the positive polarity.

3-4 Dielectric Solution

The first proposal of using dielectric solution is the tap water (TW 97.41% H_2o) and graphite powder (GP 2.59%) such that it can transport the high spark current between the tool-electrode and plate-electrode for conducting the sparks by breaking down at the appropriate applied voltage respectively. Secondly, the dielectric solution flushes out the chips from the machined area, and finally, the dielectric reduces temperature of the workpiece.

The developed EDM process for cutting BSG (non-conducting material) by using dielectric solution (tap water and graphite powder). To complete building of EDM system is shown in Fig. (5) by using available equipment like [vertical milling machine, Pyrex(5L), power supply (welding machine high current), dielectric solution 40g/L (tap water and graphite powder), tool-electrode (steel), plate-electrode (graphite), base, capacitor 5µF, and conducting wires].

Machining with EDM is a complex process influenced by several parameters, like applied voltage, current, dielectric properties and others relating to the material removal rate. The surface finish also depends on these factors as well as on the electrode material it self. Fig. (6) shows a pattern of BSG at thickness 3mm.

4- Network-Based Analysis Functions

To employ the genetic algorithm in "Simulnet" by data analysis system based on a core of neural network functions that include a genetic network,1 back propagation network, probabilistic network, and a vector quantizer network.

The experimental data were divided into two parts: one for model training and the other for testing. In the testing process, by comparing its output with a range of experimentally determined results, the error for all cases sounds reasonable to accept the model designed for further implementation. To obtain the optimum values, the number of network sizes in the input and output nodes should be set to six and one respectively. Fig. (7) shows the Structure of the hybrid system at the optimization phase.

5- Results and Discussion

Fig. (8) shows the variation of Ra on the current density at 3mm borosilicate glass thickness. An increase in current density causes a proportionate increase in the Ra, showing that the discharge currents have a large influence on the Ra. Therefore, in order to achieve better surface finish, low current density is suggested, although the machining efficiency is relatively low. At thickness 3mm the Ra is low (0.003µm) and increases with increase current density by ratio 20, 25, 28.6, 41.7 and 75% at currents 200, 250, 300, 350 and 400A respectively this may be due to the increase in gas bubble produced and temperature, as it is concluded in Refs. [5, 8, 10]. In the same currents the machining time are 78, 71, 66, 62 and 57min respectively.

5-1 Prediction of surface roughness (Ra)

5-1-1 Genetic Network (GN)

The results of training and testing data set by use of the genetic network model could predict the Ra with about 94.236% accuracy.Fig. (9) shows the scatterplot of the measured and predicted values of the Ra of 5 data sets for 3mm thickness of BSG by using GN. This indicates that the relationship between the actual and the predicted Ra is non linear. In all these data the fit between experimental and model Ra values are satisfactory.

5-1-2 Back Propagation Network (BPN)

The results of training and the testing data set by use of the BPN model could predict the Ra with about 94.034% accuracy.

Fig. (10) shows the scatterplot of the measured and predicted values by using BPN. In all these data the fit between experimental and model Ra values are satisfactory.

5-1-3 Probabilistic Network (PN)

The results of training and testing data set by use of the PN model could predict the Ra with about 96.628% accuracy.

Fig. (11) shows the scatterplot of the measured and predicted Ra values. In all these data the fit between experimental and model Ra values are finally satisfactory.

5-1-4 Vector Quantizer Network (VQN)

The results of training and testing data set by use of the VQN model could predict the Ra with about 92.8754% accuracy.

Fig. (12) shows the scatterplot of the measured and predicted values of the Ra by using vector quantizer network. In all these data the fit between experimental and model Ra values are satisfactory.

5-2 Influence of machining parameters on measured and predicted surface roughness (Ra)

In Fig. (13) the error between the curves don't exceed 17% at accuracy Ra predictions.

Fig. (14) shows the comparison of Ra among the measured values and predictions on various network models. The five curves represented the average surface roughness in both measured and predicted cases. The error between measured values and predicted values is small (under 8%). The accuracy by uses GN about 94.236%, BPN about 94.034%, PN about 96.628%, and VQN about 92.8754%. Therefore, the prediction accuracy when (Ra predicted PN) when used is higher than the other network models because the PN use of a single pass algorithm and extension is less compared with other networks.

Fig. (15) shows the effect of the test number (various network models for 5 patterns). From figures the error for Ra predicted GN, BPN, PN and VQN don't exceed 35.65833, 27.72, 24.825 and 36% respectively.

6- Conclusions

The main conclusions which can be deduced from this research can be summarized as follows:

1- The experimental tests show that non-conducting materials can be machined successfully; although all the literature being surveyed that it is impossible to machine such materials in EDM and successful EDM system has been built for this purpose.

2- The DC current needed for EDM process is substituted by AC current giving reasonable results.

3- The Al and Si powders being added to dielectric solution is replaced by graphite powder resulting in better conductivity and tap water is used in all tests rather than distilled water or oil.

4- 3mm thickness of glass (BSG) can be machined with high surface finish and dimensional accuracy and the results for the Ra in this method are about (0.003-0.012μm).

5- The software "Simulent" is well used in analyzing the experimental results and shows satisfactory analytical results for assisting the work.

6- The multiple regression models by using GN, BPN, PN and VQN could predict the surface roughness average 94.236, 94.034, 96.628 and 92.875% respectively from training data sets.

7- The difference on the Ra at different network models for 3mm thickness of BSG don't exceed (8%) respectively from testing data sets.

8- By comparison between Ra among the measured values and prediction various network models, the difference is between (1-8%) respectively.

9- The prediction accuracy by the use of PN is higher than other network models, because the probabilistic network uses a single pass algorithm and extension (complication) less from the other network models.

References

[1] Lotfi, K., G., Electrical Discharge Machining (EDM), the American University in Cairo, Department of Mechanical Engineering, Vol. 202, 2003.

[2] Ho, K., H., and Newman, S., T., State of the art electrical discharge machining (EDM), International Journal of Machine Tools and Manufacture, Vol. 43, pp. 1287-1300, 2003.

[3] John, E., F., Electrical discharge machining, Rockwell International, ASM Metals Handbook, Vol. 16 Machining, pp. 557-564, 1997.

[4] Margaret, H., C., Environmental Constituents of Electrical Discharge Machining, Submitted to the Department of Mechanical Engineering, 2004.

[5] Chen, Y., and Mahdavian, S., M., Parametric study into erosion wear in a computer numerical controlled electro-discharge machining process, Wear, Vol. 236, pp. 350-354, 1999.

[6] Deng, J., and Lee, T., Surface integrity in electro-discharge machining, ultrasonic machining, and diamond saw cutting of ceramic composites, Ceramics International, Vol. 26, pp. 825-830, 2000.

[7] Jain, V., K., et al, On the machining of alumina and glass, International Journal of Machine Tools and Manufacture, Vol.43, pp. 1269-1276, 2002.

[8] Puertas, I., et al, Analysis of the influence of EDM parameters on surface quality, MRR and EW of WC-CO, Journal of Materials Processing Technology, Vol. 153-154, pp. 1026-1032, 2004.

[9] Wuthrich, R., and Fascio, V., Machining of non-conducting materials using electrochemical discharge phenomenon-an overview, International Journal of Machine Tools and Manufacture, Vol.45, pp. 1095-1108, 2005.

[10] Puertas, I., et al, Spacing roughness parameters study on the EDM of silicon carbide, Journal of Materials Processing Technology, Vol. 164-165, pp. 1590-1596, 2005.

[11] Tsuneo, K., and Mitsuro, H., A study of EDM and ECM/ECM- lapping complex machining technology, International Journal of Machine Tools and Manufacture, Vol. 46, pp. 1804-1810, 2006.

[12] Pandey, P., C., and Shan, H., S., Modern machining processes, University of Roorkee, New Delhe, Chapter 4, pp.84-113, 1980.

[13] Hassan, El-Hoffy, Advanced Machining Processes, Chapter 5, pp.115-140, by McGraw-Hill Company, 2005.

Table (1) Machining parameters used in experimental work.

Working Parameters	Description
Workpiece	Borosilicate glass(3mm)
Tool-electrode material	Steel (6mm diameter)
Tool-electrode speed	22rpm
Shape of tool-electrode	Cylindrical bar (conical)
Tool-electrode polarity	Negative (-)
Plate-electrode material	Graphite plate(100*70*15mm)
Plate-electrode polarity	Positive (+)
Dielectric	Tap water+ graphite powder(40g/L)
Grain size of graphite powder	10µm (average)
Dielectric temperature	40-80°C
Input voltage	380V (three phase)
Output voltage	70V (two phase)
Current	200-400A

Table (2) Properties of work material [6].

Properties	Borosilicate Glass
Coefficient of thermal expansion	$32.5*10^{-6}$/K
Thermal conductivity	1.1304W/mK
Softening/Melting temperature	820°C
Density	2230Kg/m^3
Specific heat	486.1J/Kg K

Table (3) Chemical composition of AISI 1045 tool steel.

Elements	%C	%Mn	%P	%S
St. 1045	0.43-0.5	0.6-0.9	0.04max.	0.05max.

Table (4) Mechanical properties of AISI 1045 tool steel.

Density	7870Kg/m^3
Tensile strength	640MPa
Yield point	340MPa
Elongation	19%
Reduction of area	30%
Hardness	230HB
Melting temperature	1500°C

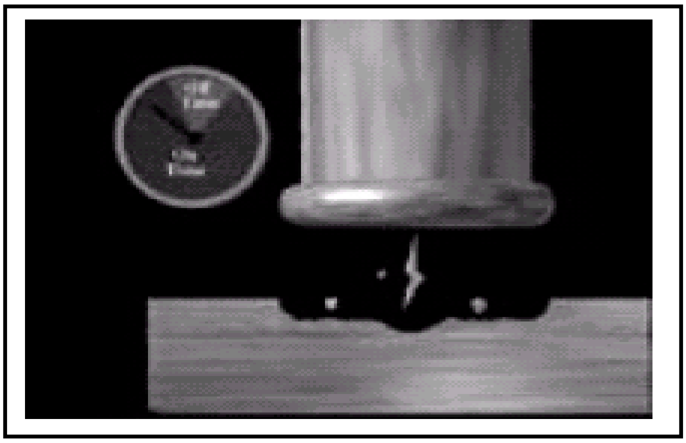

Figure (1) EDM spark [1].

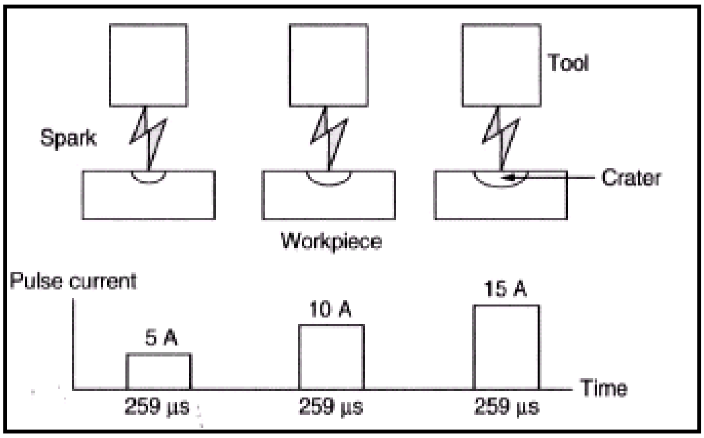

Figure (2) Effect of pulse current (energy) on removal rate and surface roughness [13].

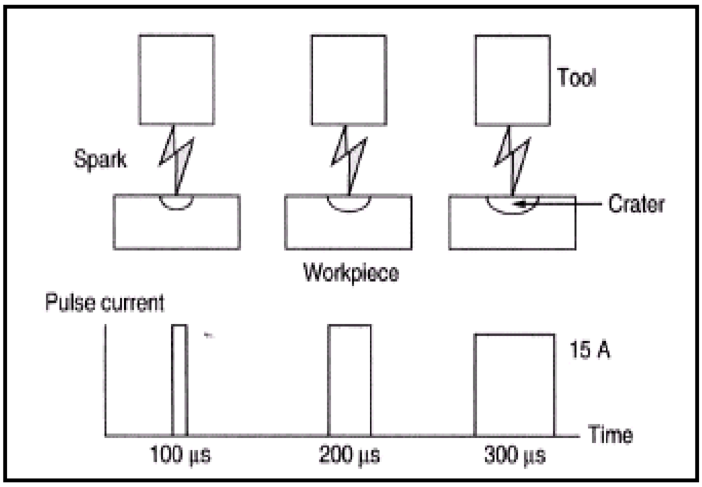

Figure (3) Effect of pulse on-time (energy) on removal rate and surface roughness [13].

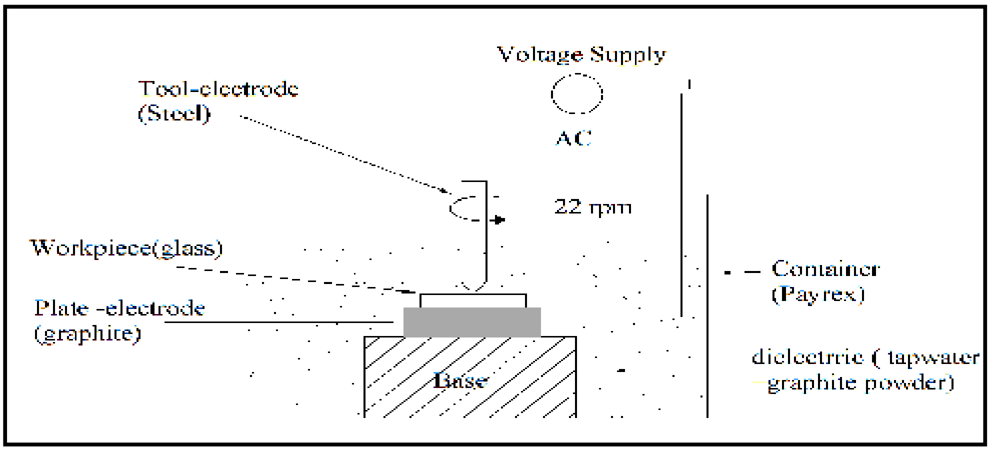

Figure (4) Schematics of the EDM for the experimental work.

Figure (5) Universal EDM machine model.

Figure (6) Pattern of BSG at thickness 3mm.

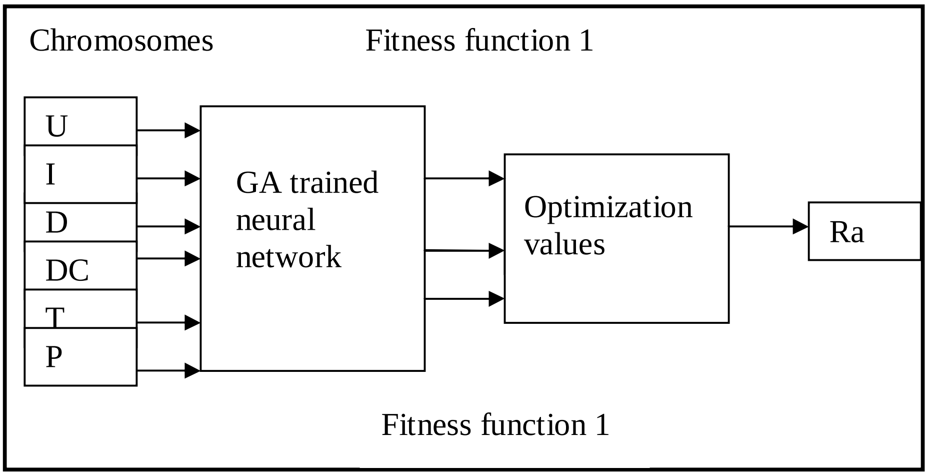

Figure (7) Structure of the hybrid system at the optimization phase.

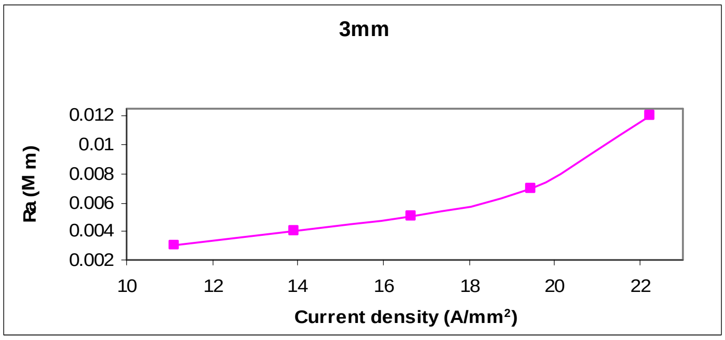

Figure (8) Effect of Ra on the current density at 3mm thickness.

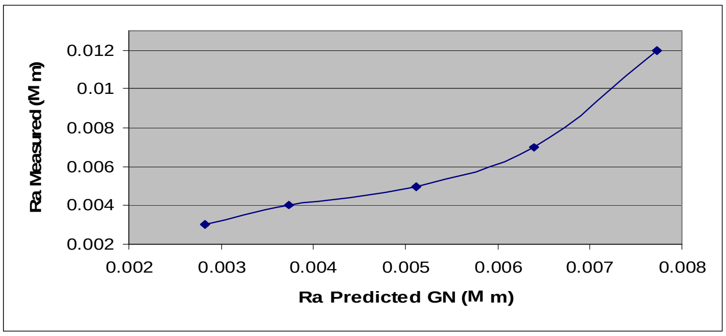

Figure (9) Scatterplot of the measured Ra and the predicted Ra by use GN.

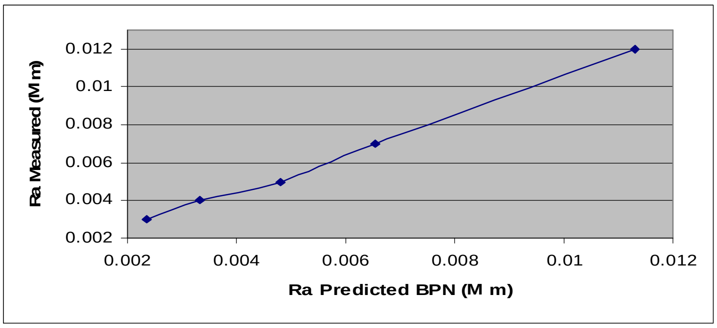

Figure (10) Scatterplot of the measured Ra and the predicted Ra by use BPN.

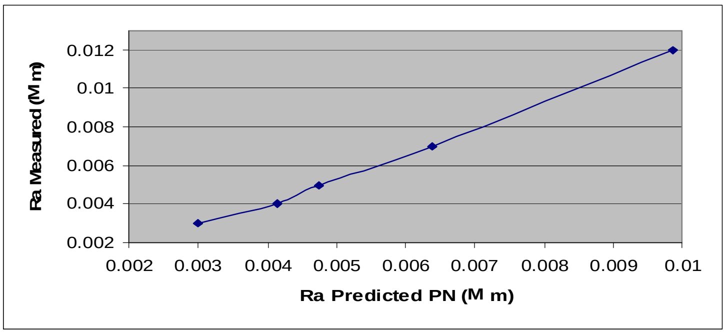

Figure (11) Scatterplot of the measured Ra and the predicted Ra by use PN.

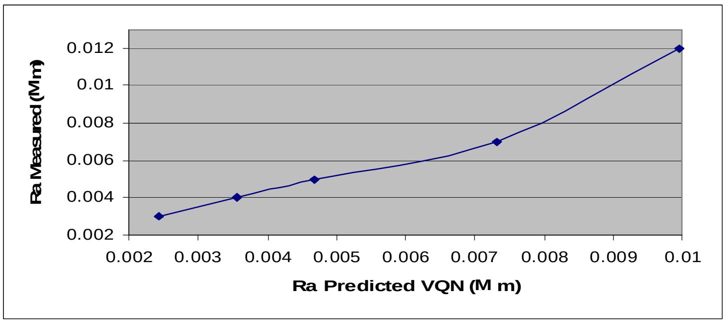

Figure (12) Scatterplot of the measured Ra and the predicted Ra by use VQN.

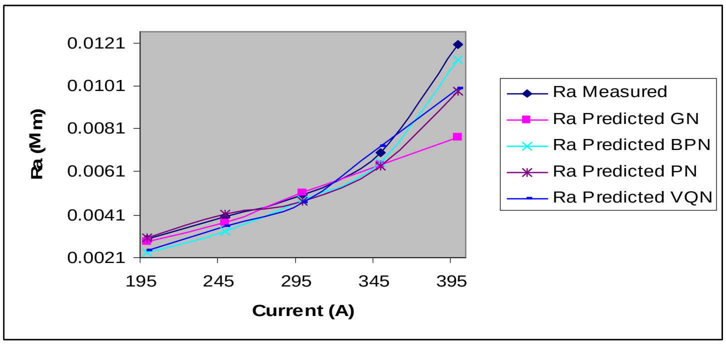

Figure (13) Effect of the current on the Ra for different network models at thickness 3mm.

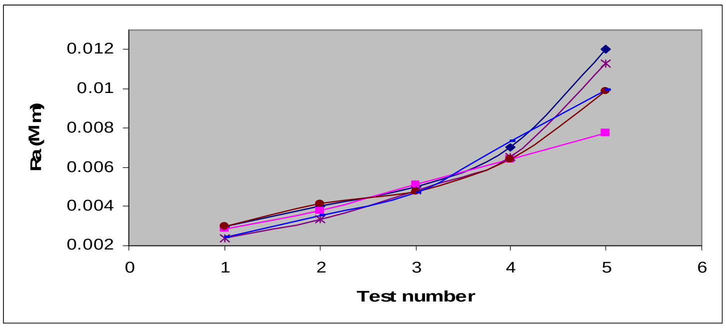

Figure (14) Comparison of Ra among the measured values and predictions on various network models.

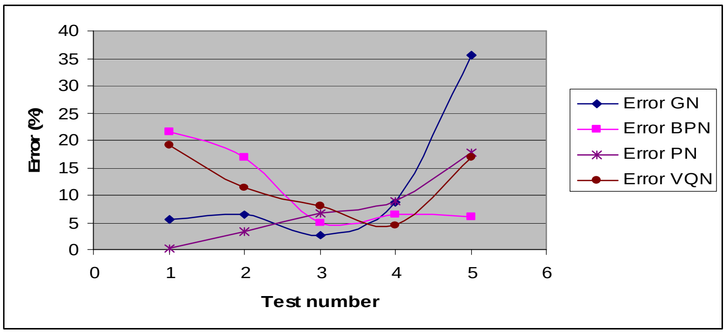

Figure (15) Effect of test number on the different error network.