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Effect of Electrical Current on Surface Roughness of Borosilicate Glass using EDM

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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.

EDM system was build for machining of non-conducting cutting materials such as glass including the use of powder (graphite) mixed for dielectric solution (tap water) by supplied DC 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).

Matlab program has been used to investigate the process control for EDM that could the Ra experimental and theoretical with accuracies of 94.236, 94.034, 96.628 and 92.875% respectively. From the reading of the magnitude of the roughness it was found that differences between the theoretical and experimental values for 3mm thickness of BSG was never exceed (8%).

Key Words: EDM, Surface Roughness, BSG, MRR, REW.

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 on-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 tools 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 achined, 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 nonconducting 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 Sm (response surface) from 59-119µm. Tsuneo and Mitsuro (2006) [11] studied the EDM and ECM complex machining technology. First, EDM shaping and CM 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.

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]:

$$Ra = 0.0225 I_p^{0.29} t_p^{0.38} \quad \ldots\ldots(1)$$

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

EXPERIMENTAL CONDITIONS

Experiments were done on EDM machine attached with a dielectric solution in the cutting laboratory of the metallurgy and production engineering department. 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 nonconventional 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 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 away from the work area by the dielectric solution.

Results and Discussion

Fig. (5) shows the variation of currents on the Ra at 3mm borosilicate glass thickness. An increase in current 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 and short discharge time are suggested, although the machining efficiency is relatively low. At thickness 3mm the Ra is low (0.003µm) and increases with increase current 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].

MatLab Program of Surface Roughness (Ra)

Fig. (6) shows the scatter plot of the theoretical and experimental values of the roughness for 3mm thickness of BSG by using Matlab program. This indicates that the relationship between the experimental and the theoretical roughness is linear. In all these data the fit between experimental and model roughness values are satisfactory. Fig. (7) shows the scatter plot of the Ra & Rae with the magnitude of current by using Matlab program. The graph indicates that the pattern of increase the current with increase in the theoretical and experimental Ra. Fig. (8) shows the scatter plot of theoretical and experimental by the magnitude of roughness with the magnitude of power by using Matlab program. The Ra & Rae increases with increase in the different power. Fig. (9) shows the scatter plot of Ra & Rae with the magnitude of machining time (MT). The graph indicates that the pattern of increase the machining time with decreases of Ra & Rae. Fig. (10) shows the flow chart of the program that was built in this research finally.

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.

2- 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).

3- The software Matlab program is well used in analyzing the experimental results and shows satisfactory analytical results for assisting the work.

4- The surface roughness average 94.236, 94.034, 96.628 and 92.875% respectively from Matlab program.

5- The difference on the theoretical and experimental values of the roughness at different network models for 3mm thickness of BSG doesn't exceed (8%) respectively.

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

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Table (1) Machining parameters used in experimentalwork.

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

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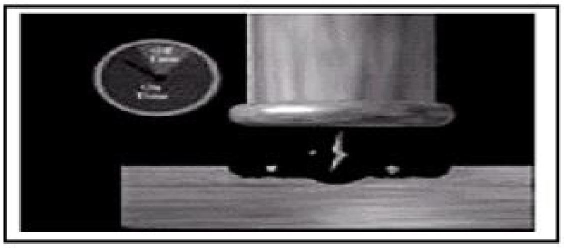

Figure (1) EDM sparks [1].

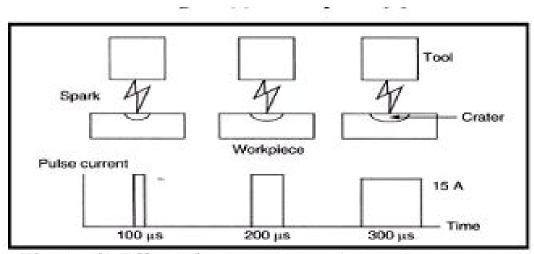

Figure (2) Effect of pulse current (energy) on removal rate and surface roughness [13].

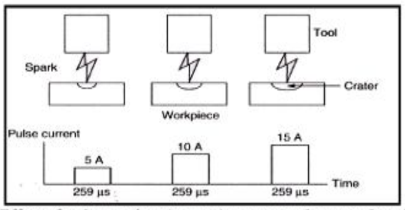

Figure (3) Effect of pulse on-time (energy) on removal rate and surface roughness

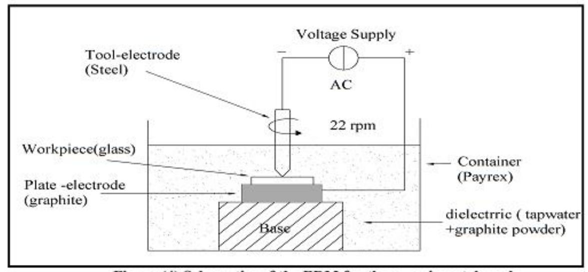

Figure (4) Schematics of the EDM for the experimental work.

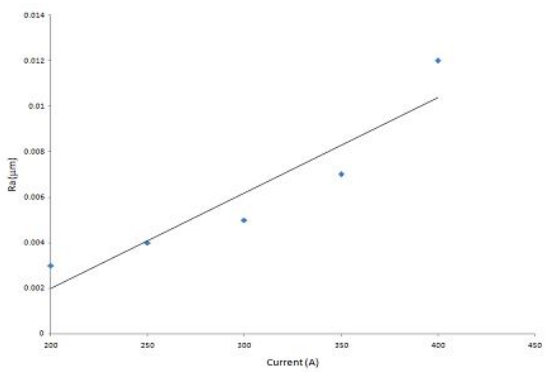

Figure (5) Effect of current on the Ra at 3mm thickness.

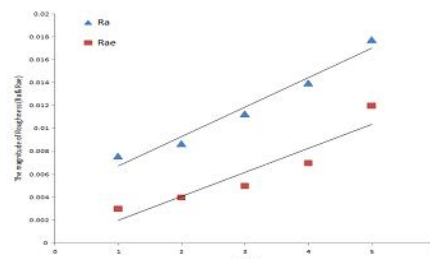

Figure (6) Explain the difference in data between theoretical (Ra) and experimental (Rae) roughness.

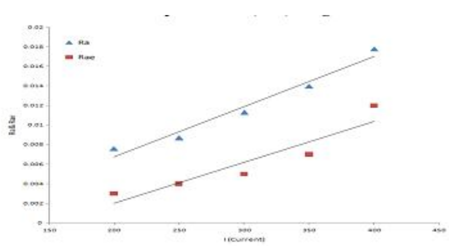

Figure (7) Explain the relation between the magnitudes of roughness (Ra & Rae) with the magnitude of current (I).

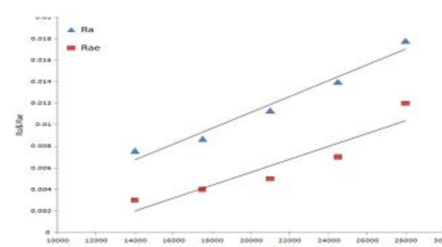

Figure (8) Explain the relation between the magnitudes of roughness (Ra & Rae) with the magnitude of power (P).

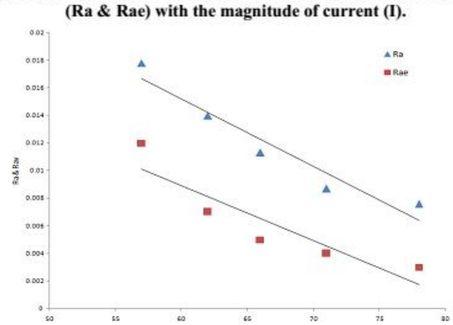

Figure (9) Explain the relation between the magnitudes of roughness (Ra & Rae) with the magnitude of machining time (MT).

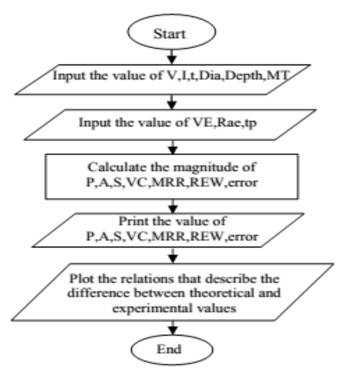

Figure (10) Explain the flow chart of the program that was built in this research.