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STUDY ON THE EFFECT OF MACHINING PARAMETERS ON ECSM OF GLASS

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ABSTRACT

To successfully compete in today's global market, the need of rapid product development reducing the lead-time between the designs of the product to its arrival in the market is increasing day by day. Moreover the market demands are changing fast. To respond to fast changes in demands, development of new innovative products is required which requires several sophisticated manufacturing processes. New machining processes are required to machine the advanced difficult-to-machine materials that are replacing the conventional materials at a very fast rate. Recently, a new trend has been introduced to combine the features of different machining processes. Such machining processes are called as Hybrid Machining Processes (HMPs).

Electro-Chemical Spark Machining (ECSM) is an evolving advanced hybrid machining process comprising the techniques of electrochemical machining (ECM) and electro discharge machining (EDM). ECSM is useful for both conducting and non-conducting materials. ECSM is a hybrid process, where the material removal is achieved by thermal and chemical processes.

In this work, an experiment on machining of glass with ECSM with different tool materials was conducted. A detailed study was also conducted to find out the influence of different machining parameters on the ECSM machining of glass and developed a mathematical model of the same.

KEYWORDS: ECSM, HMPs, Machining Parameters, Mathematical Model

INTRODUCTION

So far the research was centered towards the development of new materials such as chlorides, nitride, wasp alloy, fiber reinforced plastics etc., but at last the attention is also being paid towards the industrial manufacture of products of these new materials. Traditional cutting methods are not able to machine these materials accurately and precisely, which is the pre requirement of different industrial factories like aerospace, missiles, automobiles, nuclear reactors etc. They give rise to low tool life, fuzzing, delamination, poor quality of innovative etc. To successfully compete in today's global market, there is a dire need of rapid product development reducing the lead-time between the designs of the product to its arrival in the market. Moreover the market demands are changing fast. To respond to fast changing demands, manufacture of newly designed products requires several innovative manufacturing processes. Newer machining processes are required to machine the advanced difficult-to-machine materials (like silicon, ceramics, composites, etc.) that are fast replacing the conventional materials. Recently, a new trend has been introduced to combine the features of different machining processes. Such machining processes are called as Hybrid Machining Processes (HMPs).

Electro-chemical Spark Machining (ECSM) is an evolving advanced hybrid machining process comprising the techniques of electrochemical machining (ECM) and electro discharge machining (EDM) together. ECSM is useful for both conducting and non-conducting materials. ECSM is a hybrid process, where the material removal is achieved by thermal and chemical processes.

ELECTRO-CHEMICAL SPARK MACHINING

Electrochemical spark machining (ECSM) is a hybrid process, which employs electrochemical machining (ECM) and electro discharge machining (EDM). However, electrochemical reaction in ECS assists in case of machining of electrically non-conductive material. ECM and EDM are well-established processes and they are being used in industries for the production of components made of low machinability but electrically conducting materials. It is an emerging non-traditional processing technique that involves high-temperature melting and accelerated chemical etching under the high electrical energy discharged on the electrode tip during electrolysis.

Electrochemical spark (ECS) process is under study for the layered manufacturing in micron region. Micromachining needs are forcing reconsideration of electrochemical techniques as a viable solution. ECS is a strong candidate for micro fabrication utilizing the best of ECM and EDM together. Applications of ECS for micro fabrication can be in the field of aeronautic, mechanical, electrical and similar other engineering fabrication. The prospective use of ECS is in micro robots useful in micro surgeries and micro handling, as an inspection device, etc. Figure 1 gives the classification tree of the manufacturing processes. The branch shows the evolvement of ECS process.

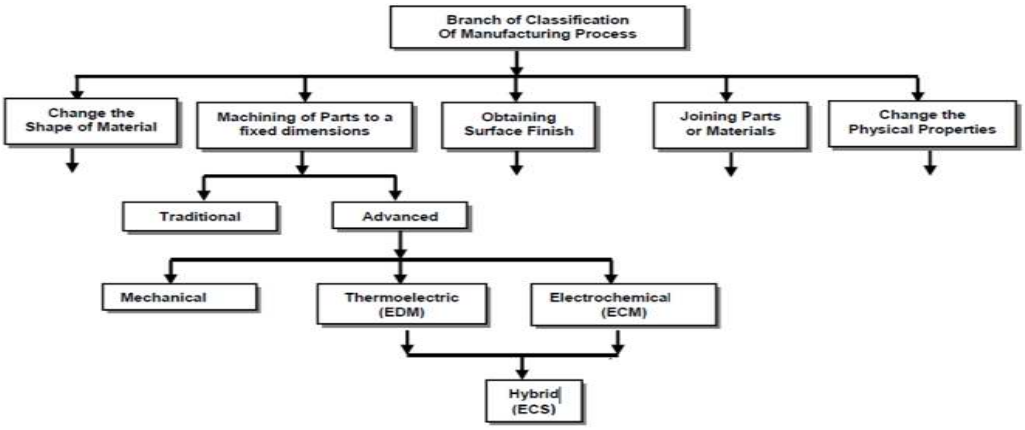

Figure 1: Evolvement of ECS (Branch in the Classification Tree of Manufacturing Process)

Electrochemical Spark Machining (ECSM) makes use of electrochemical and physical phenomena to machine. Electro-chemical spark machining (ECSM) is an emerging nontraditional processing technique that involves high-temperature melting and accelerated chemical etching under the high electrical energy discharged on the electrode tip during electrolysis. The principle is explained in the figure below

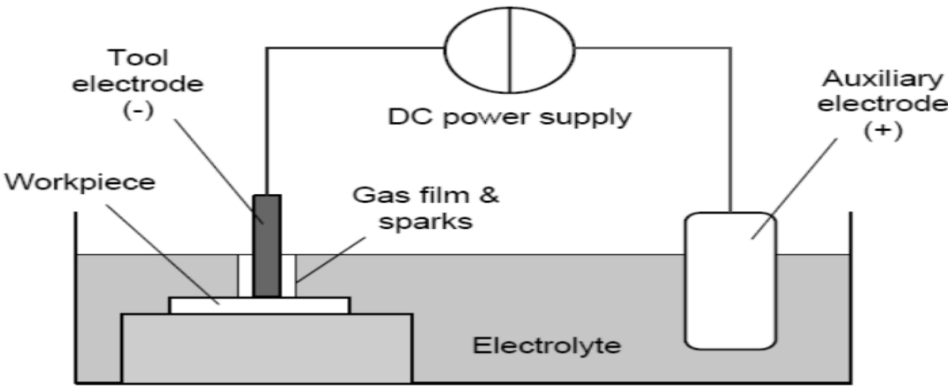

Figure 2: Principle of Electro-Chemical Spark Machining

The work piece is dipped in an appropriate electrolyte solution (typically sodium hydroxide or potassium hydroxide). A constant DC is applied between the machining tool/tool electrode (usually cathode) and the counter electrode (usually anode). The tool electrode is dipped a few millimeters in the electrolytic solution and the counter electrode is, in general, a large flat plate. The tool electrode surface is always significantly smaller than the counter-electrode surface (by about a factor of 100). The tool electrode is generally polarized as the cathode, but the opposite polarization is also possible.

When the cell terminal voltage is low, traditional electrolysis occurs. Hydrogen gas bubbles are formed at the tool electrode and oxygen bubbles at the counter electrode depending upon the electrolyte used and the electrode polarization. When the terminal voltage is increased, more bubbles are formed. When the terminal voltage is increased beyond the critical voltage, the bubbles coalesce into a gas-film around the tool-electrode. Light emission can be observed in the gas film when electrical discharges, the so called electrochemical discharges, occur between the tool and surrounding electrolyte. The mean temperature of the electrolytic solution increases in the vicinity of the tool electrode to about 80°C -90°C.

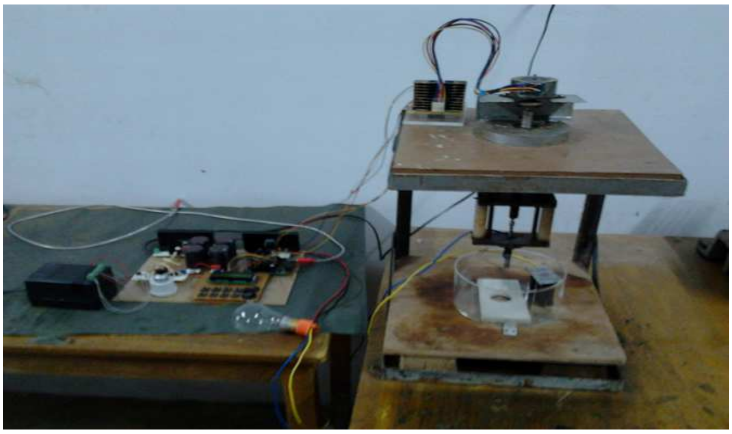

Figure 3: ECSM Machining Setup

OPTIMISATION METHODOLOGY

Optimization of parameters is done by means of Taguchi method. The first step in this method is to select the no of variables or parameters and their levels or values. The methodology for optimization is given below:

- Select the number of parameters and their levels.
- Selection of Orthogonal array.
- Selection of criteria (Higher-The-Better, Lower-The-Better, Nominal-The-Best).
- Determination of Signal to Noise ratio (S/N ratio).
- Selection of best combination of parameters for maximum Material Removal Rate.

Select the Number of Parameters and their Levels

In electrochemical spark machining process the response or result is affected by number of parameters. The parameters may be variable (voltage, current etc.) or non-variables. Optimization is done for variable as well as non-variable parameters separately or combining both parameters. In actual practice effect of each parameter is difficult to determine. Each parameter is considered separately and experimentation is done by neglecting or avoiding or not taking into consideration effect of those parameters (e.g. if effect of voltage on MRR is taken into consideration, the effect of feed rate or any other component is not considered or that parameter is considered as constant). Therefore, Taguchi has designed Orthogonal Array combining number of parameters taking number of levels or values for obtaining better combination of parameters for obtaining highest MRR.

Selection of Orthogonal Array

Orthogonal Array (OA) is determined by considering number of parameters and number of levels or values for which experiments to be run. The values or levels of these variable parameters are given in table 1. Depending upon the parameters and their levels Orthogonal Array is selected. For optimization purpose L9 Orthogonal Array is selected. The combination and values of parameters in this particular L9 orthogonal array are given in table 2.

Selection of Criteria (Higher-the-Better, Lower-the-Better, Nominal-the Best)

In case of the material removal arte the Higher-The-Better criteria is selected. For increasing productivity of the process the material removal will be more or high hence this criterion is selected.

Selection of S/N Ratio

S/N ratio for Higher-The-Better criterion is given as:

$$\frac{\mathrm{S}}{\mathrm{N}} = -10\log\frac{1}{n}\left\{1/\sum_{i=1}^{n} Yi^2\right\}$$

Selection of Best Combination of Parameters for Maximum Material Removal Rate

Calculate the S/N ratios by means of above equation. The S/N ratio having maximum value is taken as best combination of parameters for optimization. Thus the optimization of parameters is done

EXPERIMENTAL SETUP

Tools : Copper, brass, stainless steel (diameter .5mm)

Work piece : Glass (thickness 2mm)

Electrolyte : NaOH

Frequency : 8KHz

An aim of the study was to find out the effect of different factors on material removal rate (MRR) and find out which tool material is best for higher MRR. The different factors taken into consideration were duty cycle, tools, concentration of the electrolytic solution and terminal voltage. Each of the factors was varied through three levels. The details of the factors and their levels are given in the table below.

Table 1: The Various Factors and their Different Level

Factors	Level 1	Level 2	Level 3
Tools	Br	Cu	SS
Electrolyte conc.	16%	18%	20%
Voltage	140V	145V	150V
Duty cycle	50%	55%	60%

To reduce the number of experiments to a practical level, only a small set from all the possibilities is selected. The method of selecting a limited number of experiments which produces the most information is known as a fractional factorial experiment. For this, the Taguchi method was used for the Design of Experiments (DOE). In DOE, a series of structured tests are designed in which planned changes are made to the input variables of a process or system. The effects of these changes on a pre-defined output are then assessed. There are number of orthogonal arrays coined by Taguchi. In this work, the L9 orthogonal array was used to study the effect of the different factors on Material Removal Rate (MRR).

Table 2: L9 Orthogonal Array for the Experiment

Experiment No:	Tool	Electrolyte Conc:(%)	Duty Cycle(%)	Voltage (V)
1	Br	16	50	140
2	Br	18	55	145
3	Br	20	60	150
4	Cu	16	55	150
5	Cu	18	60	140
6	Cu	20	50	145
7	SS	16	60	145
8	SS	18	50	150
9	SS	20	55	140

RESULTS

The MRR obtained from the different planned experiments is given below:

Table 3: Results for Pulsating DC Machining

Exp: No:	Tool	Conc: (%)	Duty Cycle(%)	Voltage (V)	MRR (mm^3/min)
1	Br	16	50	140	.02279
2	Br	18	55	145	.05388
3	Br	20	60	150	.09668
4	Cu	16	55	150	.09851
5	Cu	18	60	140	.08404
6	Cu	20	50	145	.08464
7	SS	16	60	145	.08371
8	SS	18	50	150	.05078
9	SS	20	55	140	.05469

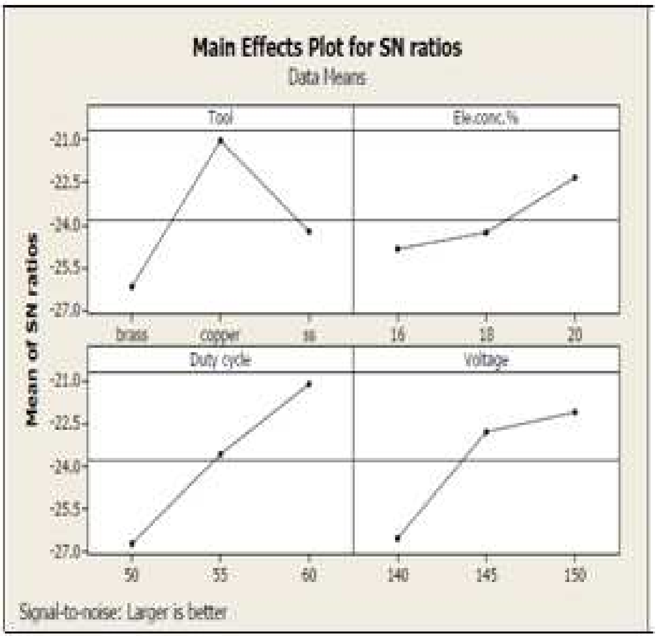

Figure 4: Main Effect Plots for SN Ratio of ECSM Process Using Pulsating DC

Table 4: Response Table for Signal to Noise Ratios

Response Table for Signal to Noise Ratios
Larger is better

Level	Tool	Ele.conc.%	Duty cycle	Voltage
1	-26.17	-24.84	-26.73	-26.53
2	-21.03	-24.26	-23.58	-22.79
3	-24.22	-22.33	-21.12	-22.10
Delta	5.14	2.51	5.61	4.43
Rank	2	4	1	3

Response Table for Means

Level	Tool	Ele.conc.%	Duty cycle	Voltage
1	0.05778	0.06834	0.05274	0.05384
2	0.08906	0.06290	0.06903	0.07408
3	0.06306	0.07867	0.08814	0.08199
Delta	0.03128	0.01577	0.03541	0.02815
Rank	2	4	1	3

From the above response table for signal to noise ratio, the highest S/N ratio value is taken as the best combination of parameters. So that level 2 value is the higher value in tool column, we can denoted it as A2, level 3 value is the higher value in electrolyte concentration column and can be denoted it as B3, level 3 value is the higher value in duty cycle column and can be denoted it as C3 and level 3 value is the higher value in voltage column and can be denoted it as D3. Thus the parameters are optimized. Optimized condition of the parameters is 1) copper tool 2) 18% electrolyte concentration 3) 60% duty cycle and 4) 150V voltage.

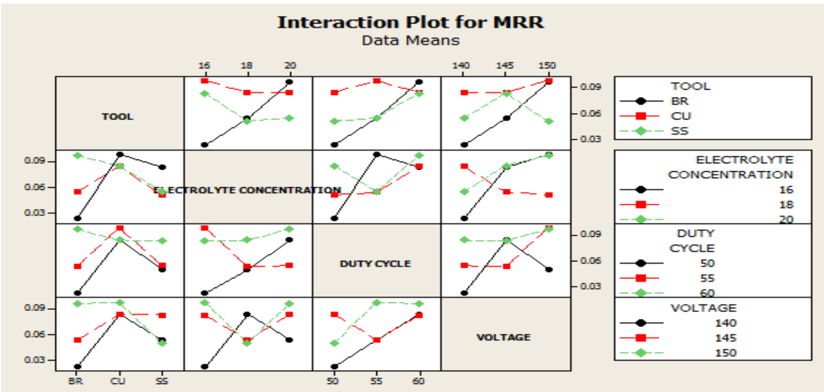

Figure 5: Interactive Plots between the Different Factors in ECSM Process Using Pulsating DC

- Copper tool shows best MRR, when it comparing with other two tool materials (brass & stainless steel).
- For all tool materials, MRR increase with increase of duty cycle.
- For all tool materials except brass tool, the MRR decreases with increasing of electrolyte concentration.
- For all tool materials except stainless steel tool, the MRR increases with increasing of voltage.
- 20%wt. NaOH is found to be optimum for machining.
- All electrolyte concentration, at 60% duty cycle shows best MRR.
- For all electrolyte concentration except 18%wt, the MRR increases with increasing of voltage.
- For all duty cycle except 55%duty cycle, the MRR increases with increasing of voltage.
- For all duty cycle except 50%, the MRR increases with increasing of electrolyte concentration.

- For all voltage, the MRR increases with increasing of duty cycle.
- At 150V, all tool materials show best MRR.

MATHEMATICAL MODELLING

A mathematical model usually describes a system by a set of variables and a set of equations that establish relationships between the variables. The values of the variables can be practically anything; real or integer numbers, Boolean values or strings, for example. The variables represent some properties of the system, for example, measured system outputs often in the form of signals, timing data, counters, and event occurrence (yes/no). The actual model is the set of functions that describe the relations between the different variable.

For Brass Tool

MRR = -.591628 + .00258333 A + .00354067 B + .002815 C

For Copper Tool

MRR = -.560348 + .00258333 A + .00354067 B + .002815 C

For Stainless Steel Tool

MRR = -.586352 + .00258333 A + .00354067 B + .002815 C

Where,

A = Electrolyte concentration, B = Duty cycle, C = Voltage

CONFIRMATION TEST

- Predicted value = .12601 mm^3/min
- Actual value = .15804 mm^3/min

CONCLUSIONS

- Copper tool shows best MRR, when it comparing with other two tool materials (brass & stainless steel).
- Value difference in the confirmation test is due to the electrolyte level difference above the work piece and temperature of the electrolyte.
- Above 150 V copper tool break the glass, while we increasing the frequency we can machine glass with copper tool with voltage greater than 150V
- Spark intensity will lower when the concentration of NaOH solution lowered.
- If frequency increases, voltage for spark also increases.
- Electrochemical spark machine can be effectively used for micro fabrication of non-conducting materials.

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