Effect of tool diameter in ECDM process with powder mixed electrolyte

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Abstract. Electro Chemical Discharge Machining (ECDM) combines the basic principles of Electro Chemical Machining (ECM) and Electro Discharge Machining (EDM) using the advantages of both the techniques to machine non-conducting, hard to machine materials like a variety of glasses, ceramics and composites. In the current paper , ECDM is carried out with powder mixed electrolyte with stales steel tool of various diameters. Output responses are measured according to MRR and ROC. From the experimental results smaller diameter tools has shown higher MRR with lower ROC.

Keywords: Electro Chemical Discharge Machining (ECDM), MRR, ROC, Gray relational analysis

1. Introduction

Hybrid machining processes facilitates new applications and opportunities for manufacturing various components which are notable to be produced economically by processes on their own. The main objectives include increasing material removal rate, improving surface integrity, reducing production time, reducing tool wear and extending application areas. By combining different machining actions or phases to be used on the material being removed the technological improvement of machining processes can be achieved. A mechanical conventional single cutting or mechanical abrasive action process can be combined with the respective machining phases of Electro Discharge (ED) in Electro Discharge Machining (EDM) or ECD in ECM. The reason for such a combination and the development of a hybrid machining process is mainly to make use of the combined advantages and to avoid or reduce some adverse effects the constituent processes produce when they are individually applied. As comparing the performance characteristics of a hybrid process with single-phase processes there is considerable difference in terms of accuracy, productivity and surface quality.

Material removal in ECDM process is by machining non-conducting material by removing material through melting or vaporization by electric arcs and sparks. Chemical reaction takes place when a DC current is applied between the electrodes separated by a small distance (0.03 to 0.07mm) and this causes formation of positively charged ionic gas bubbles. These bubbles form a dielectric space around the electrodes. At an optimum voltage the gas bubbles collapses and a current of electrons

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generated, this results in high temperature spark which erodes the material from the work piece. The material removed gets dissolved in the electrolyte. Electrolyte provides better cooling effect.

2.Literature Review

A. Kulkarni *et al*, [1] the basic ECDM phenomenon is studied and with the help of experimental observations of time-varying current in the circuit concluded the mechanism of ECDM. The basic mechanism of material removal and temperature rise is proposed based on these observations. A high electric field of the order of 107 V/m gets generated across the cathode tip and isolated electrolyte causing an arc discharge within the gas layers covering the tip. That is heat discharge region.
Basak et al. [2] have given analytical model of MRR with the experimental validation, but the basic theory of spark generation proposed by them does not match with the actual situation.
Shilpi Sharma *et.al*. [3] has conducted a review on the effective parameters electrochemical discharge machining. It was found in the researches that applied voltage is the most influential parameter for material removal rate. Electrolyte concentration is the secondary parameter affecting the Tool wear and MRR. For the better performance of ECDM the optimization techniques are required to known the optimized value of parameter. Selection and optimization of parameters is done ECDM has capability to provide better results. Lijo and Somashekhar, [4] had conducted Response Surface Modelling (RSM) of ECDM with pulsating DC to understand the effect of various process parameters on micro hole and micro channel machining for Material Removal Rate (MRR), Tool Wear Rate (TWR), Heat Affected Zone (HAZ) and Radius of Overcut (ROC). From the experiments they found that micro machining was effected by the temperature of the electrolyte. At higher depth MRR decreases due to lower spark which was due to unavailability of electrolyte. Lijo and Somashekhar [5] have also carried out multi objective optimization with grey relational analysis and micro channels have made with optimized values. They have reported that low duty factor during machining can reduce HAZ in micro channels. Lijo *et al*, [6] also reported that higher frequency at low duty factor will increase MRR with reduction in HAZ. Duty factor is found to be a predominant factor affecting the machining characteristics. Ranganayakulu *et al*, [7] developed an ECDM setup for micromachining of acrylic plate.

Despite the considerable amount of research, which has been reported on the theoretical aspects and laboratory experiments, there are many aspects of the process control issues that are yet to be investigated for the achievement of improved productivity of the ECDM process. From the literature survey it is found that ECDM is at research level only and most of the works are experimental. In this investigation experiment is carried out with powder mixed electrolyte. Tool diameters used are 0.52 and 1 mm. The input parameters selected for experiments are tool rotation, voltage (V), graphite powder concentration (%) and duty factor (%). Multi-objective optimization has been carried out using Gray relational analysis. The output parameters selected are Material Removal Rate (MRR) and Radial Over-Cut (ROC). The confirmation tests are conducted based on the best parameter combinations. The effect of tool diameter on output responses are studies in the current paper.

3.Experimental setup

Important components of ECDM machining setup are tool electrode, counter electrode, workpiece, DC source and end sensing part. The performance of ECDM in terms of rate of machining and surface finish is affected by many factors. As far the metal removal mechanism of an ECDM process is concerned, it is necessary to control the gap width, electrolyte flow rate, temperature of the electrolyte, electrolyte concentration and pulse parameters of the pulsed power supply at an optimum level to obtain higher performance in terms of machining accuracy, the surface finish and the metal removal rate. Figure1 shows the ECDM set up.

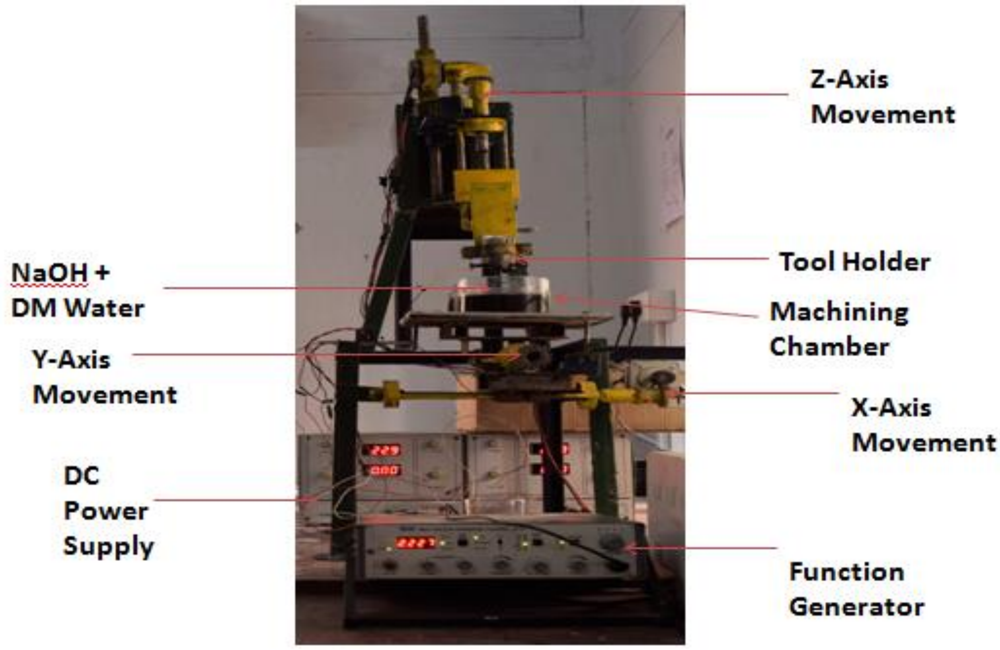

Figure 1 ECDM Setup.

3.1 Tool electrode

Tool will acts as the cathode. At the negative electrode where a high electron potential have been produced via an external voltage source, electrons are pushed out of the electrode, thereby reducing the oxidised species, because the electron energy level inside the electrode(Fermi level) is higher than the energy level and the electrons can lower their energy by occupying this orbital. So the negative electrode will be the one where reduction reaction will take place and thus its called cathode. Tungsten copper alloy of diameter 0.52 mm and 1 mm is used for tool electrode in electro chemical discharge machining process.

3.2 Counter electrode

A rectangular graphite piece of dimension 40*40*10 mm is used as the counter electrode in ECDM process. Graphite is an electrically conductive form of solid carbon. At the positive electrode where low electrons potential have been produced via an external voltage source, electrons are sucked into the electrode leaving behind the reduced species. So the positive electrode will be the one where oxidation reaction will take place and thus it is called anode.

3.3 Workpiece

Borosilicate glass is used as a workpiece material in this ECDM investigation. Borosilicate glass is a type of glass with silica and boron trioxide as the main glass-forming constituents. Borosilicate glasses are known for having very low coefficients of thermal expansion and thermal shock, more so than any other common glass.

Table 1 Properties of the Workpiece

Sl No	Properties/Specifications	Borosilicate Glass
1	Thickness(mm)	0.52
2	Melting point(˚C)	820
3	Density(g/cm^2)	2.23
4	Specific heat(J/kg K)	775
5	Thermal conductivity(W/mK)	1.13

3.4 Tool feeding mechanism

The ECDM set up consists of a 3- axis tool feeding mechanism. The three axis movements are provided with the help of 3 stepper motors. Power is supplied to the stepper motors with the help DC power supply through the power circuit. The rotational motion of the stepper motor is converted into linear movement with the help of worm and worm wheel set up. Here the worm is fixed on to the stepper motor shaft and the worm wheel is fixed on to the framework.

3.5 Machining chamber

Acrylic material was used for the preparation of the chamber. There is also a work holding set up inside this beaker. Workpiece can be easily clamped on to this set up. The chamber can be clamped on to the machining table of the experimental set up using nuts and bolts.

3.6 Electrolyte

Electrolyte concentration is an important factor that influences machining. In this experiment electrolyte is taken as a mixture of NaOH pellets and DM water. The total capacity of the chamber is 650ml. The amount of electrolyte is taken as 500ml where NaOH is of 150 gm and DM water is of 350 ml i.e the electrolyte concentration is 30%.

4. Experimental investigation

Design of experiment is a powerful analysis tool for modelling and analyzing the influence of control factors on performance output. The initial step in the Taguchi model development is to build up an input-output database required for the optimization through the ECDM experiments. In order to have complete knowledge of ECDM process over the range of parameters selected, proper planning of experimentation is essential to reduce the cost and time. Hence an experimental plan based on Taguchi orthogonal array (L9) was chosen. The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer.

5. Design of experiments

The machining tests were conducted on electrochemical discharge machining (ECDM). The experiments with tool rotation were conducted on Borosilicate glass. The process parameters selected for the experiments without tool rotation are voltage (V), graphite powder concentration (%) and duty factor (%). The process parameters selected for the experiments with tool rotation are voltage (V), graphite powder concentration (%), duty factor(%) and RPM.

Voltage is provided to produce spark at the tool tip. MRR increases with increase in voltage. With increase in applied voltage, the machining current in the inter electrode gap increases, the spark rate and bubble formation will increase which leads to enhancement of MRR. For optimal radial overcut, applied voltage have been found out as the most important ECDM parameter. Graphite is used as the powder to be mixed with the electrolyte. Graphite particles are conductive and presence of conductive particles in the electrolyte can reduce the formation of micro cracks and fractures on the machined surface of the workpiece to a certain extend. Duty factor is the ratio of machine on time to the total time. Normally maximum duty factor increases the material removal rate and reduces the radial overcut. Three sets of experiments were planned to be carried out:

- One set of experiments with tool diameter of 1 mm.
- One set of experiments with tool diameter of 0.52 mm and tool rotation.

The experiments were conducted with varying tool diameters in order to obtain holes in the micro-level. The experiments were conducted with and without tool rotation. The machining parameters selected for the experimentation without tool rotation are Voltage(V), Graphite powder concentration(%) and Duty factor(%).The machining parameters selected for the experimentation with tool rotation are Voltage(V), Graphite powder concentration(%), Duty factor(%) and tool rotation with three levels. The three levels for each parameters are as follows:

Table 2 Input factors with their levels.

Sl No	Factor/Level	1	2	3
1	Voltage(V)	35	40	45
2	Graphite Conc. (%)	0	0.25	0.5
3	Duty factor (%)	60	70	80
4	Rotation(RPM)	100	300	500

Four factors (voltage, concentration, duty factor, rotation) with three levels are considered. From this input factors experimental design of L9 orthogonal array is constructed with the help of MINITAB software.

Based on the levels of the process parameters selected, the experimental plan is developed using L9 orthogonal array. According to L9 orthogonal array, the experiments are conducted. The experiments are conducted by varying each of the process parameters according to the experimental plan with tool of 1 mm diameter as given in Table 3.

Table 3 Experimental layout plan of L9 orthogonal array.

Sl.No	Voltage(V)	Graphite Conc. (%)	Duty Factor (%)
1	35	0	60
2	35	0.25	70
3	35	0.5	80
4	40	0	70
5	40	0.25	80
6	40	0.5	60
7	45	0	80
8	45	0.25	60
9	45	0.5	70

The experimental details for are given in table 4.

Table 4 Experimental details for L9 experiments.

Sl No	Item	Specifications
1	Tool	Tungsten copper alloy
2	Tool diameter	1 mm, 0.52 mm
3	Counter electrode	Graphite block
4	Dimension	(40*40*10) mm
5	Workpiece	Polypropylene(1.3 mm thick)
6	Electrolyte	NaOH + DM water
7	NaOH pellets	30% of 500 ml(150 gms)
8	DM water	350 ml
9	Powder mixed	Graphite powder
10	Process parameters	Voltage(V),Graphite powder conc(%), Duty factor and tool rotation(tool diameter 0.52mm)

Based on the levels of the process parameters selected, the experimental plan is developed using L9 orthogonal array. A set of nine experiments will be generated with different process parameter combinations. According to L9 orthogonal array, the experiments are conducted. The experiments are conducted by varying each of the process parameters according to the experimental plan. The experimental plan based on the orthogonal array for tool of 0.52 mm is provided in Table 5 below:

Table 5 Experimental layout plan of L9 orthogonal array.

Sl No	Voltage(V)	Graphite Conc.(%)	Duty Factor(%)	Rotation(RPM)
1	35	0	60	100
2	35	0.25	70	300
3	35	0.5	80	500
4	40	0	70	500
5	40	0.25	80	100
6	40	0.5	60	300
7	45	0	80	300
8	45	0.25	60	500
9	45	0.5	70	100

6. Multi-Objective Optimization

Multi-objective optimization is the process in which the optimum levels of different input parameters are found out to provide the best output parameters. Multi-objective optimization can be applied to processes having more than one output. In Multi-objective optimization, the values of output parameters are processed through different steps in order to find out the best input conditions. In this investigation, the output parameters selected are material removal rate (MRR) and radial overcut (ROC). A higher value for MRR and a lower value for ROC is required for the best

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combination. Therefore a higher preference is given for MRR and less preference is given for ROC. The multi-objective optimisation technique used is Gray Relational Analysis

7. Results and Discussions

Multi-objective optimisation has been done on the two output parameters MRR and ROC based on Gray relational analysis. The best parameter combination has been obtained from multi-objective optimisation and confirmation tests have been conducted.

7.1 EXPERIMENTAL ANALYSIS

Material Removal Rate (MRR) and Radial Over-Cut (ROC) have been calculated for each of the experiments based on the experimental observations and microscopic images.

7.2 Experiment set 1 (Tool diameter= 1mm)

Table 6 Experimental observations for experiments with tool diameter = 1mm.

Sl No	Voltage(V)	Graphite Conc(%)	Duty Factor(%)	MRR(mg/min) $*10^{-4}$	ROC(micons)
1	35	0	60	1.34	183
2	35	0.25	70	0.68	156
3	35	0.5	80	0.21	121
4	40	0	70	1.8	96
5	40	0.25	80	1.2	176
6	40	0.5	60	0.93	154
7	45	0	80	0.45	89
8	45	0.25	60	3.98	97
9	45	0.5	70	1.98	110

The experiments were conducted according to the L9 orthogonal array and two outputs MRR and ROC were obtained. Higher MRR and least ROC is preferred in micromachining of holes so that better accuracy is obtained. Higher MRR show that better machining characteristics have been taken place and is required for better results. ROC is a defect that has to be minimised in machining of micro holes. ROC is the deviation of actual hole size from the required hole size. From the above observation table we can find that the maximum MRR obtained is $3.98*10^{-4}$ mg/min and the least ROC obtained is 89 microns.

Based on the experimental observations the signal to noise ratios for MRR and ROC has been generated from MINITAB software. The normalised signal to noise ratios and deviation sequences has been calculated as per the equations in gray relational analysis. Also the gray relational coefficient and gray relational grade has been calculated and ranked according to priority.

Table 7 Ranking for grades in experiment set 1.

Experiment	GRG	Rank
1	0.275	7
2	0.392	2
3	0.287	6
4	0.193	9
5	0.345	5
6	0.382	3
7	0.266	8
8	0.587	1
9	0.372	4

Table 8 Response table of parameters for experiment set 1.

Voltage	0.7342	1.0893	1.2447
Graphite Conc	0.9328	1.1251	1.0103
Duty factor	0.9371	1.0827	1.3341

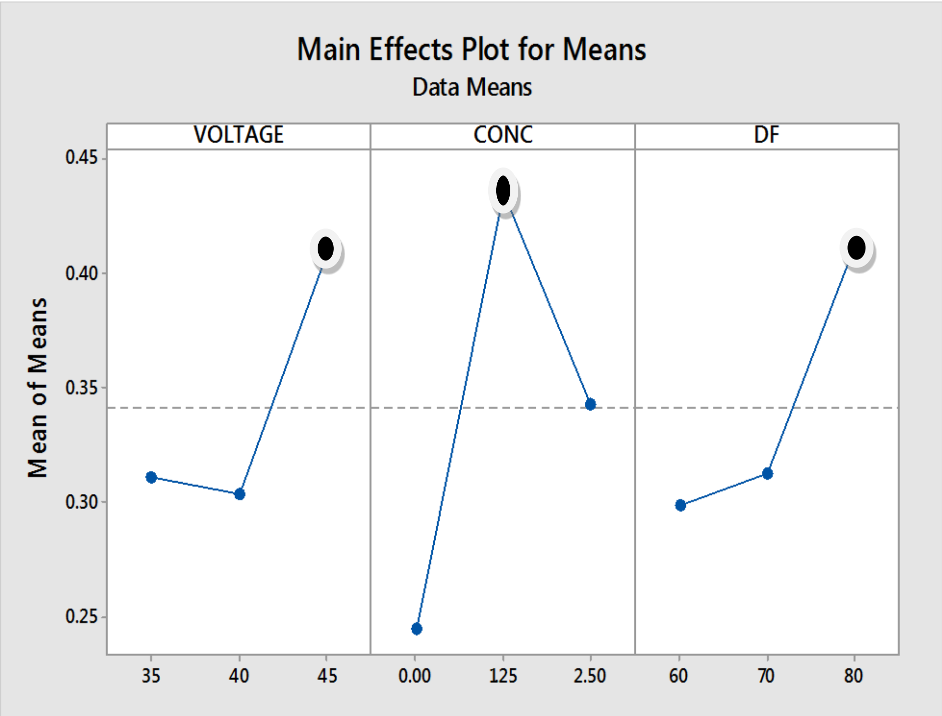

Figure 2 Main effects plot for average (set 1)

(i) Confirmation test

The best parameter combination obtained from multi-objective optimisation of experiment set 1 are:

- Voltage = 45V
- Graphite powder conc. =1.25 gms(0.25%)
- Duty factor = 80%

Maximum MRR obtained from L9 set=$3.98*10^{-4}$ mg/min
Least ROC obtained from L9 set =89 microns

MRR obtained from confirmation test = 3.85*10^{-4} mg/min
ROC obtained from confirmation test = 86 microns

7.3 Experiment set 2(Tool diameter= 0.52mm)

Table 9 Experimental observations for experiments with tool diameter = 0.52mm

Sl No	Voltage (V)	Graphite Conc (%)	Duty Factor(%)	RPM	MRR(mg/min) *10^{-4}	ROC(micons)
1	35	0	60	100	1.53	1260
2	35	0.25	70	300	1.10	1372
3	35	0.5	80	500	2.75	910
4	40	0	70	500	1.55	960
5	40	0.25	80	100	3.82	860
6	40	0.5	60	300	2.89	897
7	45	0	80	300	7.30	530
8	45	0.25	60	500	7.50	770
9	45	0.5	70	100	0.81	1453

The experiments were conducted according to the L9 orthogonal array and two outputs MRR and ROC were obtained. Higher MRR and least ROC is preferred in micromachining of holes so that better accuracy is obtained. Higher MRR show that better machining characteristics have been taken place and is required for better results. ROC is a defect that has to be minimised in machining of micro holes. ROC is the deviation of actual hole size from the required hole size. From the above observation table we can find that the maximum MRR obtained is 7.50*10^{-4} mg/min and the least ROC obtained is 530 microns. When driven by an external voltage applied to the electrodes, the ions in the electrolyte are attracted to an electrode with the opposite charge and charge transferring reaction can take place. The occurrence of spark depends upon the electrolyte concentration.

Based on the experimental observations the signal to noise ratios for MRR and ROC has been generated from MINITAB software. The normalised signal to noise ratios and deviation sequences has been calculated as per the equations in gray relational analysis. Also the gray relational coefficient and gray relational grade has been calculated and ranked according to priority.

Table 10 Ranking for grades in experiment set 2.

Experiment	GRG	Rank
1	0.214	9
2	0.286	6
3	0.258	8
4	0.299	4
5	0.305	3
6	0.261	7
7	0.298	5
8	0.402	1
9	0.382	2

Table 11 Response table of parameters for experiment set 2.

Voltage	0.8024	0.852	1.054
Graphite conc	0.758	1.0063	0.9412
Duty factor	0.9454	0.9663	0.8774
RPM	0.9013	0.8185	0.9857

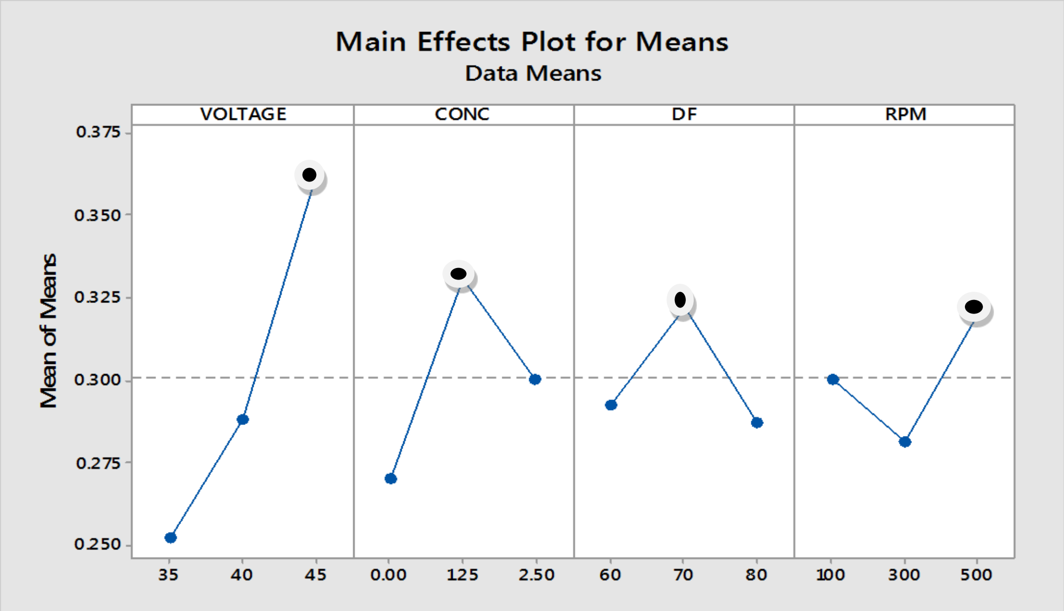

Figure 3 Main effects plot for Average (set 3)

(i) Confirmation test

The best parameter combination obtained from multi-objective optimisation of experiment set 1 are:

- Voltage = 45V
- Graphite powder conc. =1.25 gms(0.25%)
- Duty factor = 70%
- Speed = 500 rpm

Maximum MRR obtained from L9 set=7.50*10^{-4} mg/min
Least ROC obtained from L9 set =530 microns
MRR obtained from confirmation test = 7.56*10^{-4} mg/min
ROC obtained from confirmation test = 528 microns

8. Conclusion

In current study, experiments were conducted with and without tool rotation. Powder Mixed Electro-Chemical Discharge Machining process (PM-ECDM) has been carried out to perform the experiments using Graphite powder as the powder to be mixed in the electrolyte. The process parameters selected for experiments without tool rotation are voltage (V), Graphite powder concentration (%) and Duty factor (%). The process parameters selected for experiments with tool rotation are voltage (V), Graphite powder concentration (%), Duty factor (%) and Rotation (RPM).

Machining was conducted based on L9 orthogonal array. MRR and ROC were taken as the output parameters for both the experiment sets. Multi-objective optimisation using Gray relational analysis was carried out in order to obtain the best parametric combination. Based on the optimised parametric conditions, confirmation tests have been carried out. The best parameter combination obtained for experiments without tool rotation are 45 V, 0.25 % Graphite powder concentration and 80% Duty factor. The best parameter combination obtained for experiments with tool rotation are 45 V, 0.25 % Graphite powder concentration, 70% Duty factor and 500 rpm.

The confirmation test with tool rotation shows a higher MRR value ($7.56*10^{-4}$ mg/min) when compared with the MRR value ($3.85*10^{-4}$ mg/min) of confirmation test without tool rotation. The reason is that; with tool rotation the surface contact between the tool tip and the workpiece is more when compared with that of without tool rotation. Therefore more debris is removed faster while machining. Thus, it can be interpreted that tool rotation provides higher material removal rates. The confirmation test with tool rotation shows a higher ROC value (530 microns) when compared with the ROC value (89 microns) of confirmation test without tool rotation. The reason is that, with tool rotation a larger area comes in contact with the tool due to its rotational motion. This can lead to increase in the hole size from the required hole diameter. The confirmation test shows that the tool rotational speed can be increased beyond 500 rpm since the optimum value for rotation is its maximum value. Thus tool rotation increases both MRR and ROC. Also from the experimental results tool with 0.52 mm diameter has shown higher MRR with lower ROC, due to higher spark rate and tool rotation during machining process.

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