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STUDY OF PROCESS PARAMETERS IN EDM USING GREY RELATIONAL ANALYSIS

K.S.Sreenivsan[1], S. Kathiresan[2] , D.A.Premkumar[3], C. Nandakumar[4]
[1]*(Assistant Professor, Department of Mechanical Engineering,Karpaga Vinayaga College of Engineering and Technology, Tamil Nadu, India)*
[2]*(Professor, Department of Mechanical Engineering,Karpaga Vinayaga College of Engineering and Technology, Tamil Nadu, India)*
[3]*(PG Scholar, Department of Mechanical Engineering,Karpaga Vinayaga College of Engineering and Technology, Tamil Nadu, India)*
[4]*(Assistant Professor, Department of Production Technology, MIT, Anna University, Tamil Nadu, India)*

ABSTRACT: *This paper presents an effective approach to study process parameters in electrical discharge machining. Electrical Discharge Machining (EDM) is frequently used in machining of precision and intricate parts and in machining of hard materials and micro-machined features. Due to the nature of the process, parameters influence the final quality characteristics. This study presents the influence of the main EDM process parameters pulsed current, pulsed time and pulsed pause time are carried out in Aluminum Silicon Carbide (AlSiC) alloy using different tool geometrical shapes of copper electrodes. In addition to this, Material Removal Rate (MRR), Tool Wear Rate (TWR) and different dimensional and geometrical micro-accuracies are analyzed through statistical methods. Since the process has multiple performance characteristics, the grey relational analysis is used. A grey relational grade obtained from the grey relational analysis is used to optimize the process parameters.*
Keywords*—orthogonalarray,Greyrelationalanalysis, optimisition*

I. INTRODUCTION

EDM is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive. Moreover no direct contact occurs between the work piece and the tool, thus eliminating the problems such as wear, stresses and chatter associated with the conventional processes.

In EDM, a potential difference is applied between the tool and work piece. Both the tool and the work material are to be conductors of electricity. The tool and the work material are immersed in a dielectric medium. Generally kerosene or de ionized water is used as the dielectric medium. A gap is maintained between the tool and the work piece. Depending upon the applied potential difference and the gap between the tool and work piece, an electric field would be established. Generally the tool is connected to the negative terminal of the generator and the work piece is connected to positive terminal. As the electric field is established between the tool and the job, the free electrons on the tool are subjected to electrostatic forces. If the work function or the bonding energy of the electrons is less, electrons would be emitted from the tool (assuming it to be connected to the negative terminal). Such emission of electrons are called or termed as cold emission. The “cold emitted” then accelerated electrons towards the job are through the dielectric medium. As they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and dielectric molecules. Such collision may result in ionization of the dielectric molecule depending upon the work function or ionization energy of the dielectric molecule and the energy of the electron. Thus, as the electrons get accelerated, more positive ions and electrons would get generated due to collisions.

This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap. The concentration would be so high that the matter existing in that channel could be characterized as“plasma”.The electrical channel would resistance be very less. thus all of a sudden, a large number of electrons will flow from the tool to the job and ions from the job to the tool. This is called avalanche motion of electrons. Such movement of electrons and ions can be visually seen as a spark. Thus the electrical energy is dissipated as the thermal energy of the spark. The high speed electrons then impinge on the job and ions on the tool. The kinetic energy of the electrons and ions on impact with the surface of the job and tool respectively would be converted into thermal energy or heat flux. Such intense localized heat flux leads to extreme instantaneous confined rise in temperature which would be in excess of 10,000 degree Celsius.Such localised extreme rise in temperature leads to material removal. Material removal occurs due to instant vapourisation of the material as well as due to melting. The molten metal is not removed completely but only partially. As the potential difference is withdrawn the plasma channel is no longer sustained. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.

II. GREY RELATIONAL ANALYSIS

Grey analysis uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey, hazy or fuzzy. Therefore, a grey system means that a system in which part of information is known and part of information is unknown. With this definition, information quantity and quality form a continuum from a total lack of information to complete information –from black through grey to white. Since uncertainty always exists, one is always somewhere in the middle, somewhere between the extremes, somewhere in the grey area

Grey analysis then comes to a clear set of statements about system solutions. At one extreme, no solution can be defined for a system with no information At the other extreme, a system with perfect information has a unique solution. In the 18 middle, grey systems will give a variety of available solutions. Grey analysis does not attempt to find the best solution, but does provide techniques for determining a good solution, an appropriate solution for real world problems

III. TAGUCHI METHOD

Essentially, traditional experimental design procedures are too complicated and difficult to use. A large number of experimental works must be carried out when the number of process parameters increases. To solve this problem, Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Genichi Taguchi is the developer of the Taguchi method. The Taguchi method has been widely utilized in engineering analysis and consists of a plan of experiments with the object of acquiring data in a controlled way in order to obtain information about the behavior of the given process. The greatest advantage of this method is to save the effort of conducting experiments, i.e. to save the experimental time, to reduce the cost, and to find out the significant factors fast.

IV. EXPERIMENT

4.1 Experimental plan

Taguchi methods, which combine experiment design theory and the quality loss function concept, have been used in developing robust designs of products and processes and in solving some confusing problems of manufacturing. The orthogonal array selected L_9 (3^4) where each row corresponds to a particular experiment (treatment combination) and each column identifies settings of design parameters as follows in Table 1. In the first run for example, the three design variables are set at their lower level (level=1); while in the second run, the first parameter is set at level 1 and the remaining two parameters are set at high levels (level=2) and so on. For the purpose of observing the degree of influence of machining conditions (current, pulse on time, pulse off time, tool electrode geometry), four factors, each at three levels, are taken into account as shown in table 2. An analysis of variance of the data on the Aluminum silicon carbide was done on the objective of analyzing the influence of current, pulse-on time, pulse-off time and tool electrode geometry on the total variance of results.

Table 1 EDM Process Parameters and Levels

PARAMETERS	LEVELS		
	L1	L2	L3
Current (I)	08	11	14
Pulse on-time (T_{on})	19	29	38
Pulse off-time (T_{off})	05	07	09
Tool electrode geometry	circle	square	rectangle

Table 2 Orthogonal array L_9 (3^4) of Taguchi

EXPERIMENT NUMBER	PARAMETERS			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3 $L_9(3^4)$ Orthogonal Array of Cutting Conditions

EXPERIMENT NUMBER	PARAMETERS			
	1	2	3	4
1	19	05	08	Circle
2	19	07	11	Square
3	19	09	14	Rectangle
4	29	05	11	Rectangle
5	29	07	14	Circle
6	29	09	08	Square
7	38	05	14	Square
8	38	07	08	Rectangle
9	38	09	11	Circle

4.2The workpiece

Aluminium-Silicon Carbide is a metal-ceramic composite material consisting of silicon carbide particles dispersed in a matrix of aluminium alloy. It combines the benefits of high thermal conductivity of metal and low CTE (coefficient of thermal expansion) of ceramic. Surface finishing and surface grinding is done on both sides of the obtained sheet to make the two surfaces parallel to each other. The work piece has a density of 2.64 g/cc.

4.3 The cutting tool

The electrode used is copper. It has a density of 8.92 g/cc. Few of the properties of commercially available electrolytic copper are tabulated below

V. MACHINABILITY STUDY

The results obtained from each of the experiments are discussed.
A picture of the work piece after machining is shown.

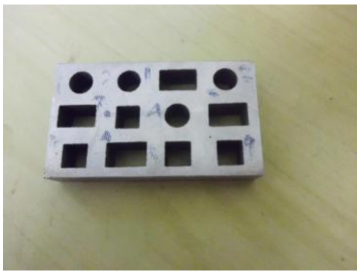

Fig. 1 The Machined Work piece

5.1 Material removal rate

Material Removal Rate in cubic millimeters is used to evaluate the machining parameter.
The MRR is expressed as:

$$MRR = WRW / (\rho \times T)$$

Where WRW is the Work piece Removal Ra work piece in gram per cubic millimeter and T is the machining time in minutes.

5.1.1 Contour graphs

Contour plots have been drawn of Material Removal Rate with regard to the process parameters such as pulse-on time, current, pulse-off time, tool geometry. All the possible combinations of the parameters considered are taken as independent variables. Each of them is explained below.

Contour plot of MRR vs Current, Pulse-on time

material removal rate is maximum when the value of current lies between 13.8A to 14.0A while the pulse on time lies between 37.5μs to 38.0μs.It is also inferred that it is not advisable to have the value of current in the range of 8.0A to 10.0A and the pulse on time in the range of 19μs to 19.5μs because the material removal rate is minimum at this range

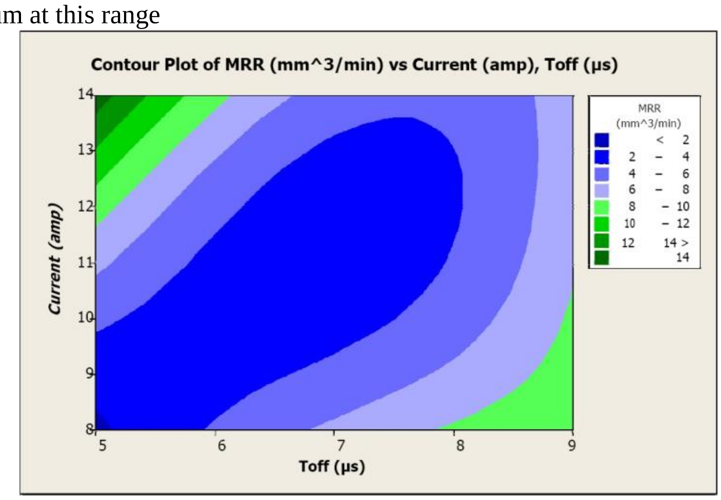

Fig. 2 Contour plot of MRR vs Current, Pulse-off time

Material removal rate is maximum when the value of current lies between 13.8A to 14.0A whiles the pulse off time lies between 5.0µs to 5.1µs. It is also inferred that it is not advisable to have the value of current in the range of 8.0A to 8.5A and the pulse off time in the range of 5.0µs to 5.3µs because the material removal rate is minimum at this range.

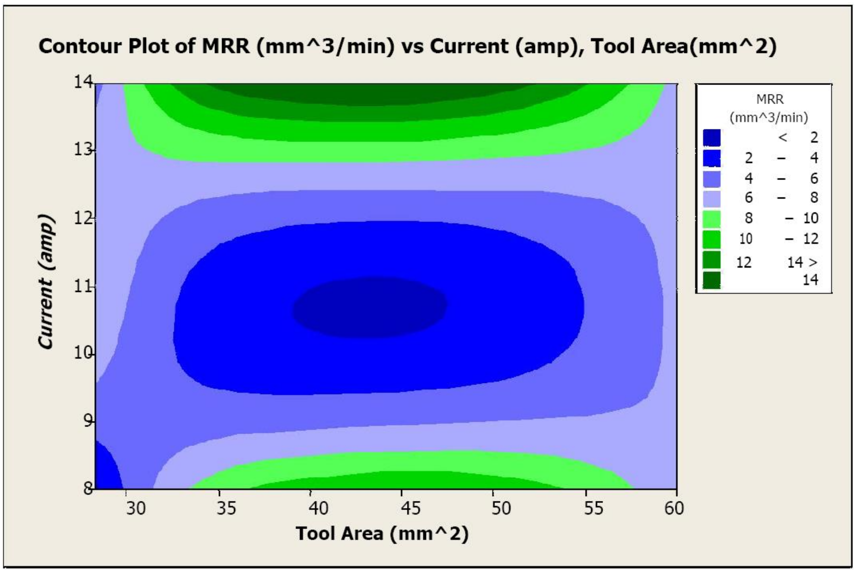

Fig. 3 Contour plot of MRR vs Current, Tool geometry

Material removal rate is maximum when the value of current lies between 13.7A to 14.0A while the tool area lies between 34.5mm^2 to 53.0mm^2. It is also inferred that it is not advisable to have the value of current in the range of 10.3A to 11.0A and the tool area in the range of 40.0mm^2 to 48mm^2 because the material removal rate is minimum at this range.

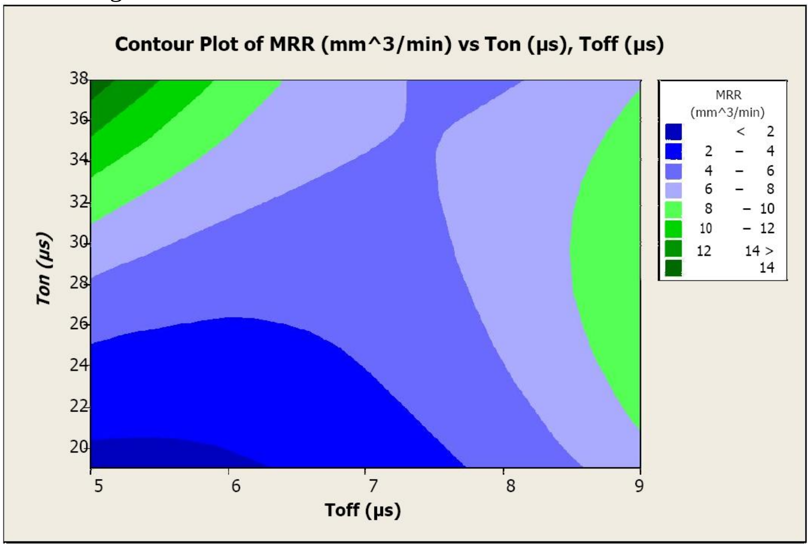

Fig.4 Contour plot of MRR vs Pulse-on time, Pulse-off time

Material removal rate is maximum when the value of pulse on time lies between 37.5.0µs to 38.0µs while the pulse off time lies between 5.0µs to 5.2µs. It is also inferred that it is not advisable to have the value of pulse on time in the range of 18.0µs to 20.0µs and the pulse off time in the range of 5.0µs to 6.3µsbecause the material removal rate is minimum at this range

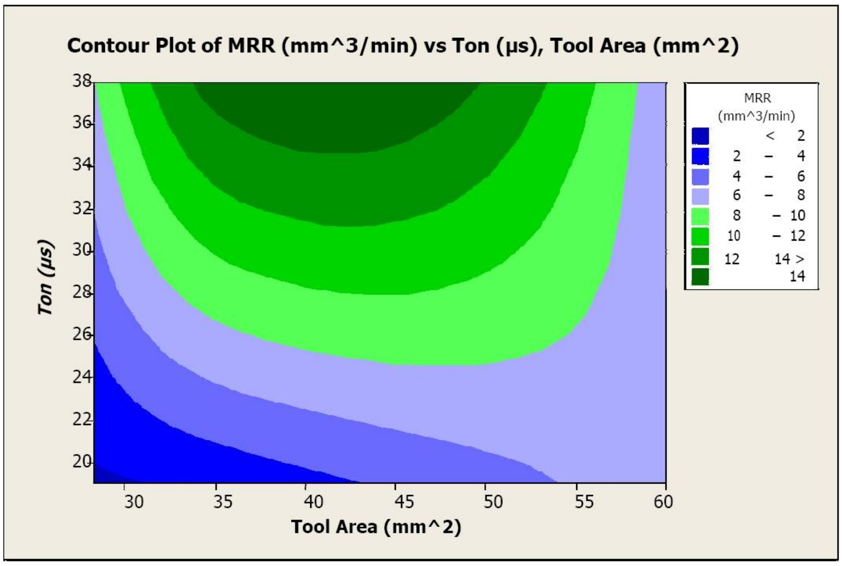

Fig. 5 Contour plot of MRR vs Pulse-on time, Tool geometry

Material removal rate is maximum when the value of pulse on time lies between 35.0µs to 38.0µs while the tool area lies between 35.0mm^2 to 50.0mm^2. It is also inferred that it is not advisable to have the value of pulse on time in the range of 18.0µs to 20.0µs and the tool area in the range of 28.0mm^2 to 31.0 mm^2 because the material removal rate is minimum at this range.

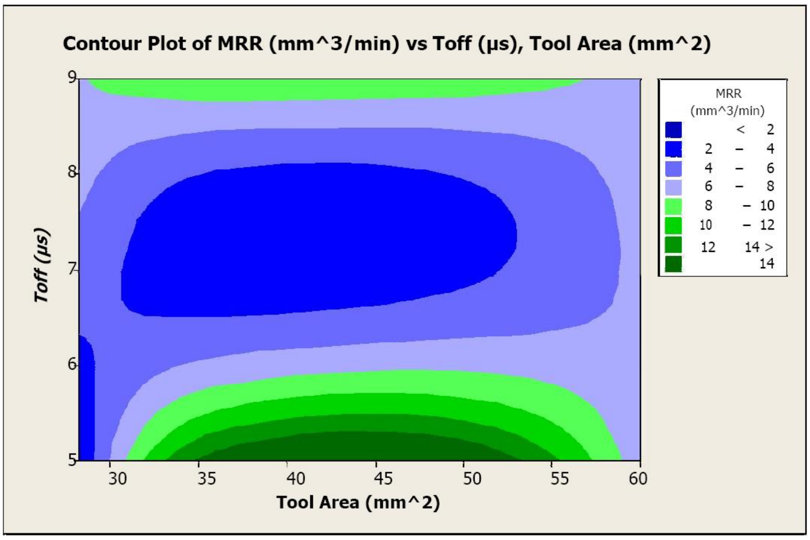

Fig. 6 Contour plot of MRR vs Pulse-off time, Tool geometry

material removal rate is maximum when the value of pulse off time lies between 5.0µs to 5.3µs while the tool area lies between 35.0 mm^2 to 53.0 mm^2. It is also inferred that the material removal rate is relatively more in this plot.

5.2 Tool wear rate

In the present investigation, the Tool Wear Rate in cubic millimeters is used to evaluate the machining parameter. The TWR is expressed as

$TWR = TWW / (\rho \times) T$

Where TWW is the Tool Wear Rate in grams, ρis the density of the tool in gram per cubic millimeter and T is the machining time in minutes.

5.2.1 Contour graphs

Contour plots have been drawn of Tool Removal Rate with regard to the process parameters such as pulse-on time, current, pulse-off time, tool geometry. All the possible combinations of the parameters considered are taken as independent variables. Each of them is explained below

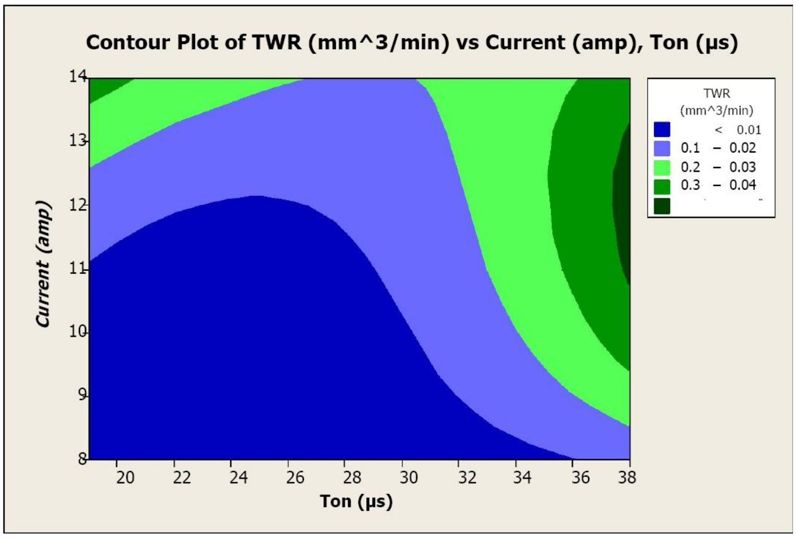

Fig. 7 Contour plot of TWR vs Current, Pulse-on time

Tool wear rate is minimum the value of current lies between 8.0A to 12.0A while the pulse on time lies between 18.0µs to 36.0µs. It is also inferred that it is not advisable to have the value of current in the range of 10.9A to 13.2A and the pulse on time in the range of 37.8µs to 38.0µs because the tool wear rate is maximum at this range.

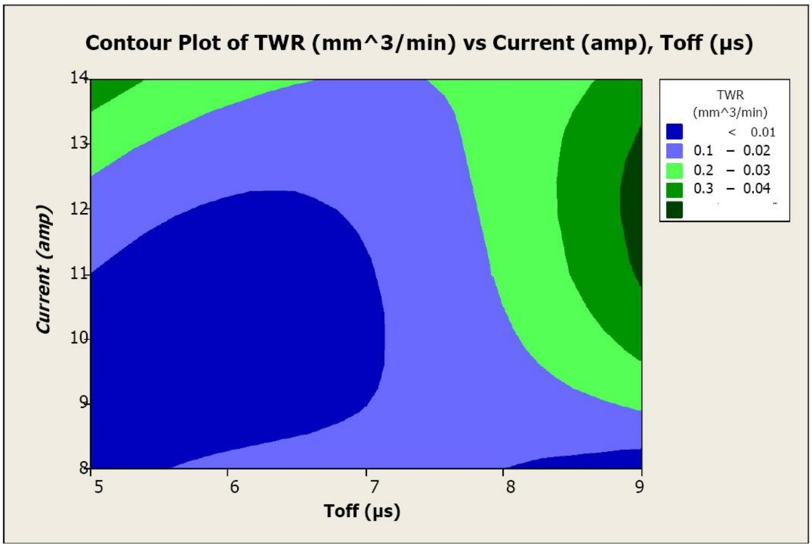

Fig. 8 Contour plot of TWR vs Current, Pulse-off time

tool wear rate is minimum at two regions when (i) the value of current lies between 8.0A to 12.0A while the pulse off time lies between 5.0µs to 7.0µs (ii) the value of current lies between 8.0A to 8.3A while the pulse off time lies between 8.1µs to 9.0µs.It is also inferred that it is not advisable to have the value of current in the range of10.5A to 13.2A and the pulse off time in the range of 8.8μs to 9.0μs because the tool wear rate is maximum at this range.

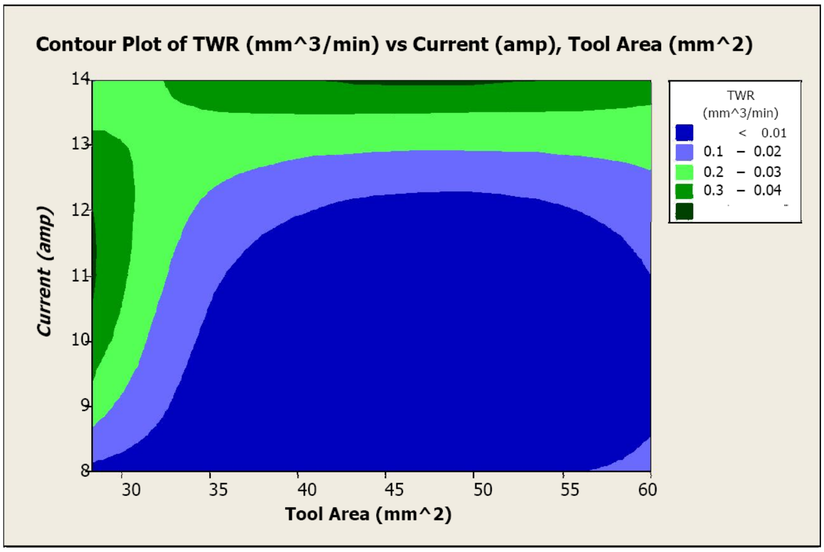

Fig. 9 Contour plot of TWR vs Current, Tool geometry

There are two regions in this contour plot where the tool wear rate is minimum the value of current lies between 8.0A to 12.0A while the tool area lies between 28.0 mm^2 is to 60.0 mm^2. It is also inferred that it is not advisable to have (i) the value of current in the range of 10.8A to 12.0A and the tool area in the range of 28.0 mm^2 to 28.2 mm^2 (ii) the value of current in the range of 13.9A to 14.0A and the tool area in the range of 40.0 mm^2 to 53.0 mm^2 because the tool wear rate is maximum at this range.

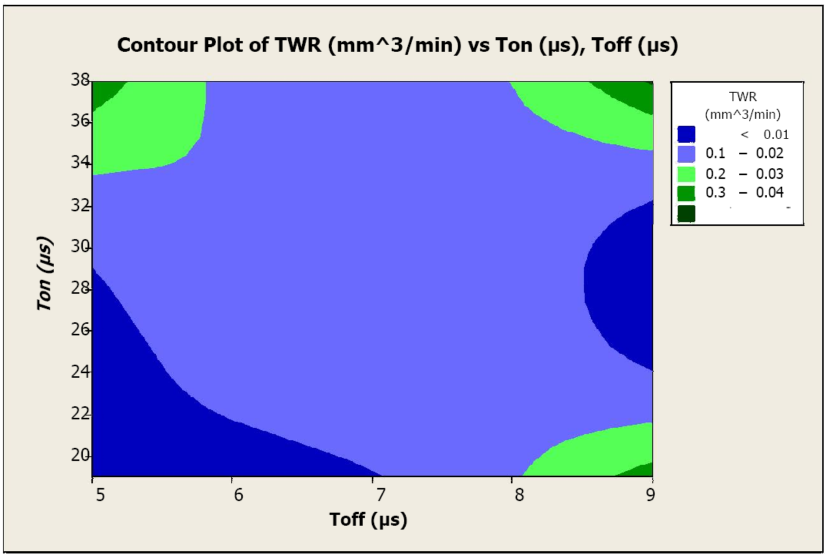

Fig. 10 Contour plot of TWR vs Pulse-on time, Pulse-off time

tool wear rate is minimum at two regions when (i) the value of pulse on time lies between

18.0µs to 29.0µs while the pulse off time lies between 5.0µs to 7.0µs (i) the value of pulse on time lies between 24.0µs to 32.0µs while the pulse off time lies between 8.5µs to 9.0µs .It is also inferred that the tool wear rate is relatively less in this plot.

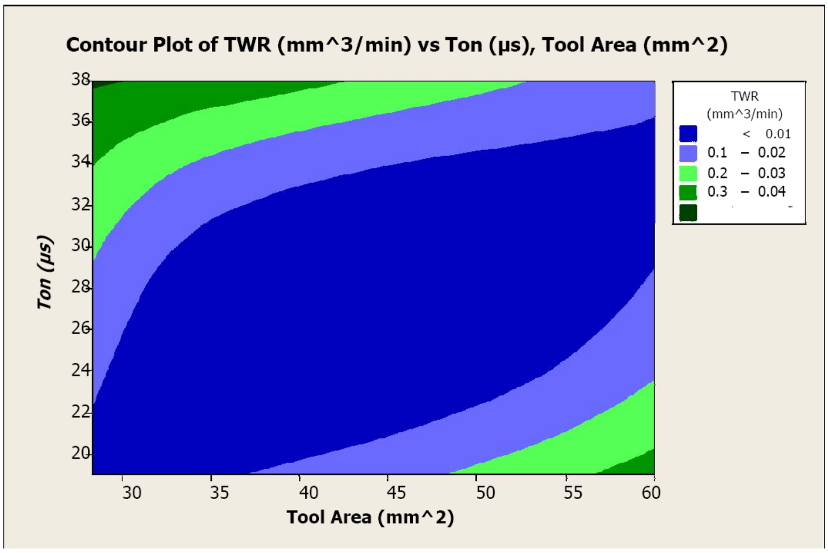

Fig. 11 Contour plot of TWR vs Pulse-on time, Tool geometry

Tool wear rate is minimum when the value of pulse on time lies between 18.0µs to 36.0µs while the tool area lies between 27.0 mm^2 to 60.0 mm^2. It is also inferred that it is not advisable to have the value of pulse on time in the range of 37.8µs to 38.0µs and the tool area in the range of 27.0 mm^2 to 29.0 mm^2 because the tool wear rate is maximum at this range.

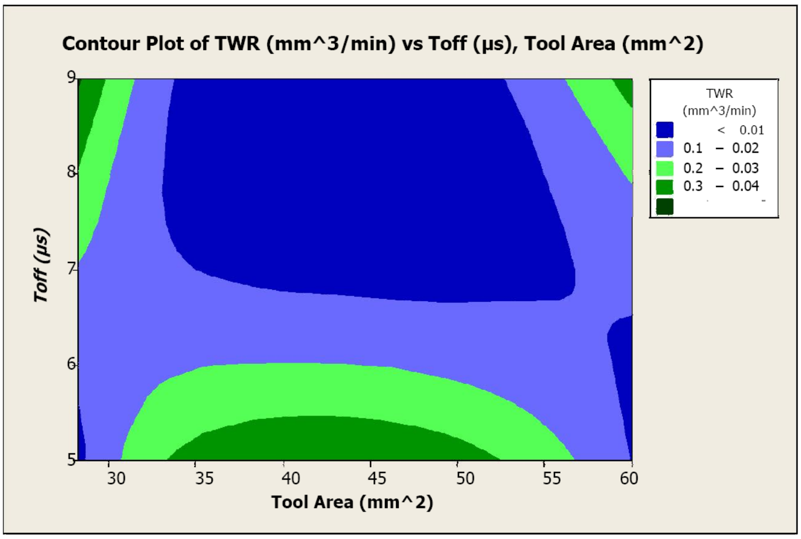

Fig. 12 Contour plot of TWR vs Pulse-off time, Tool geometry

There are three regions in this contour plot where the tool wear rate is minimum (i) the value of pulse off time lies between 6.8µs to 9.0µs while the tool area lies between 34.0 mm^2 to 57.0 mm^2 (ii) the value of pulse off time lies between 5.0µs to 6.3µs while the tool area lies between 58.0 mm^2 to 60.0 mm^2 (iii) the value of pulse off time lies between 5.0µs to

5.3μs while the tool area lies between 27.0mm^2 to 28.0mm^2. It is also inferred that the tool wear rate is relatively less in this plot.

5.3 Deviation between entrance and exit

The deviation between entrance and exit (DVEE), otherwise known as taper is measured using a Co-ordinate Measuring Machine (CMM). The Co-ordinate Measuring Machine calculates the length and width of the hole at entrance and then it calculates the length and width of the hole at the exit. For a circular hole, it calculates the diameter at the entrance and then the diameter at the exit. Lesser the deviation between the entrance and exit of a hole, better is the machining process. The DVEE for each hole was calculated and tabulated as shown below.

5.3.1 Contour graphs

Contour plots have been drawn of Deviation from Entrance to Exit (DVEE) with regard to the process parameters such as pulse-on time, current, pulse-off time, tool geometry. All the possible combinations of the parameters considered are taken as independent variables. Each of them is explained below.

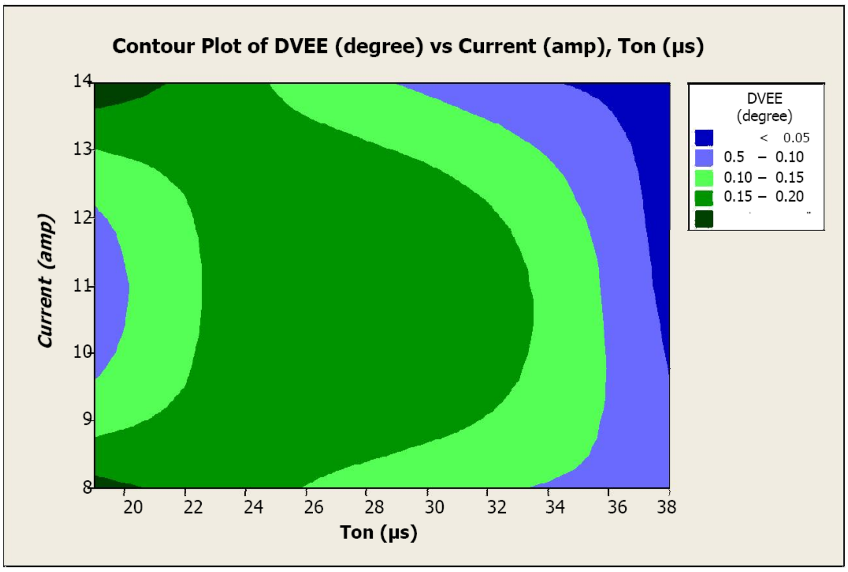

Fig. 13 Contour plot of DVEE vs Current, Pulse-on time

DVEE is minimum when the value of current lies between 10.0A to 14.0A while the pulse on time lies between 35.0μs to 38.0μs .It is also inferred that it is not advisable to have (i) the value of current in the range of 8.0A to 8.1A and the pulse on time in the range of 18.0μs to 20.0μs (ii) the value of current in the range of 13.8A to 14.0A and the pulse on time in the range of 18.0μs to 22.0μs because the DVEE is maximum at this range.

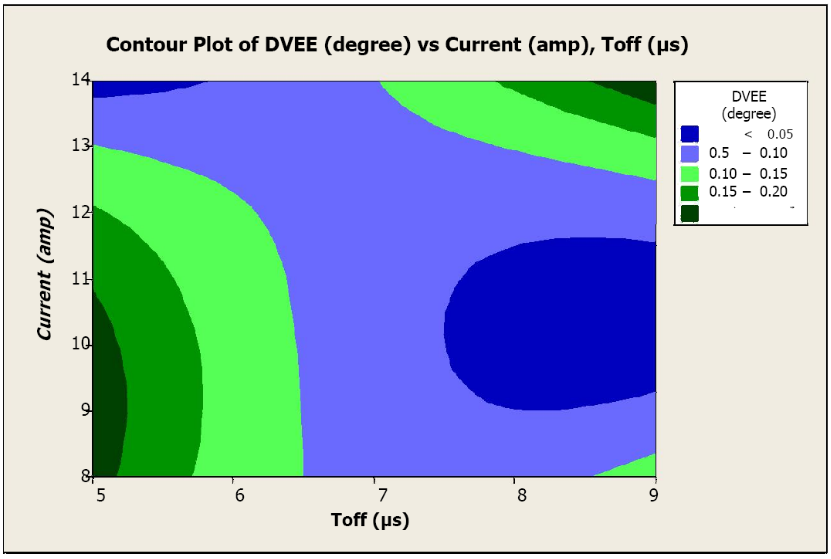

Fig. 14 Contour plot of DVEE vs Current, Pulse-off time

DVEE is minimum at two regions when (i) the value of current lies between 13.8A to 14.0A while the pulse off time lies between 5.0µs to 5.9µs (ii) the value of current lies between 9.0A to 11.5A while the pulse off time lies between 7.6µs to 9.0µs.It is also inferred that it is not advisable to have (i) the value of current in the range of 8.0A to 10.9A and the pulse off time in the range of 5.0µs to 5.2µs (ii) the value of current in the range of 13.7A to 14.0A and the pulse off time in the range of 8.5µs to 9.0µs because the DVEE is maximum at this range.

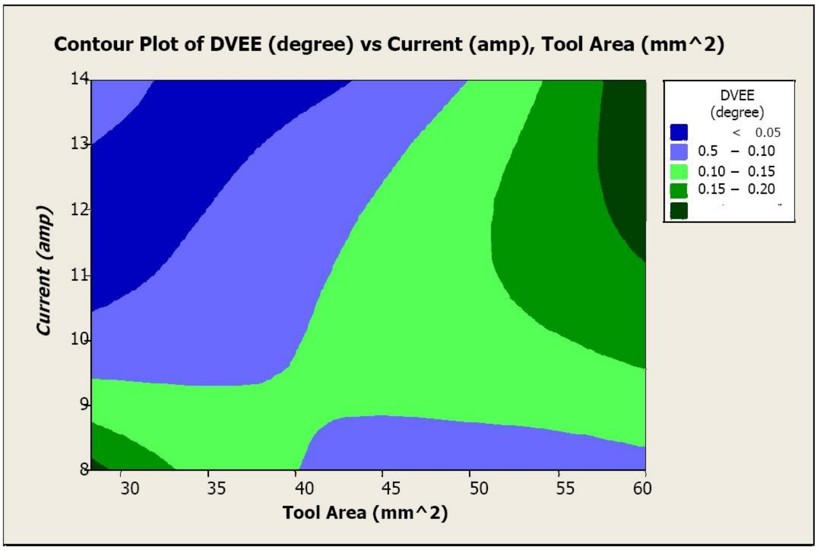

Fig. 15 Contour plot of DVEE vs Current, Tool geometry

DVEE is minimum the value of current lies between 10.5A to 14.0A while the tool area lies between 28.0mm^2 is to 43.0mm^2.It is also inferred that it is not advisable to have (i) the value of current in the range of 8.0A to 8.1A and the tool area in the range of 28.0mm^2 to 29.0mm^2 (ii) the value of current in the range of 11.0A to 14.0A and the tool area in the range of 57.0mm^2 to 60.0mm^2 because the DVEE is maximum at this range.

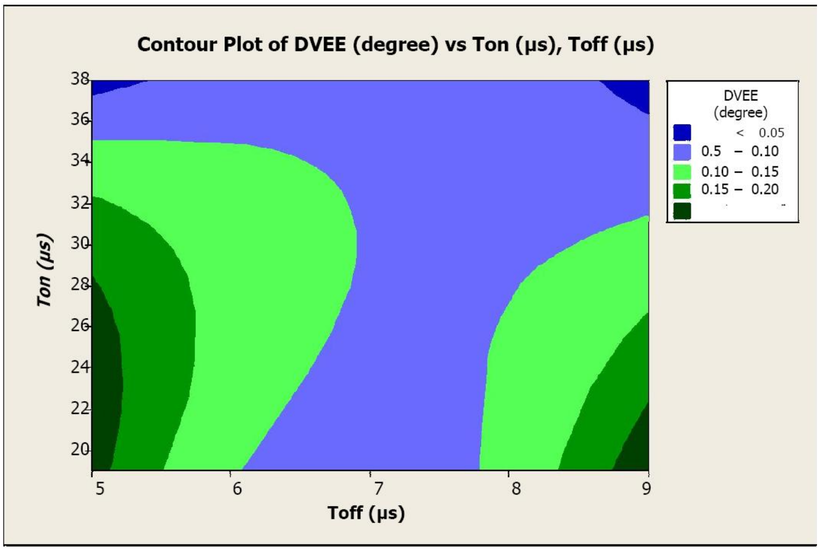

Fig. 16 Contour plot of DVEE vs Pulse-on time,pulse-off time

DVEE is minimum at two regions when (i) the value of pulse on time lies between 37.5µs to 38.0µs while the pulse off time lies between 5.0µs to 5.4µs (ii) the value of pulse on time lies between 36.0µs to 38.0µs while the pulse off time lies between 8.7µs to 9.0µs.It is also inferred that it is not advisable to have (i) the value of pulse on time in the range of 18.0µs to 28.0µs A and the tool area in the range of 5.0µs to 5.3µs (ii) the value of current in the range of 18.0µs to 22.0µs and the tool area in the range of 8.8µs to 9.0µs because the DVEE is maximum at this range.

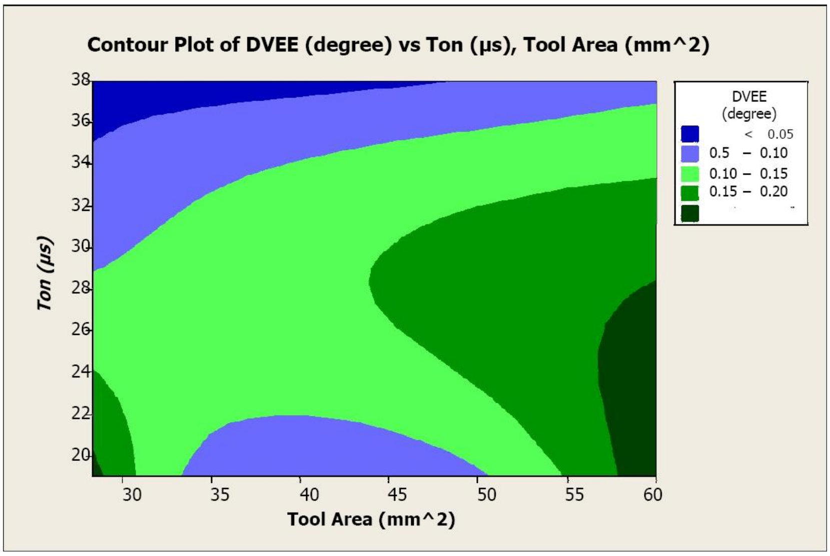

Fig. 17 Contour plot of DVEE vs Pulse-on time, tool geometry

DVEE is minimum when the value of pulse on time lies between 35.0µs to 38.0µs while the DVEE lies between 28.0mm^2 to 46.0mm^2. It is also inferred that it is not advisable to have (i) the value of pulse on time in the range of 19.0µs to 20.0µs and the tool area in the range of 27.0mm^2 to 28.0mm^2 because the DVEE is maximum at this range.

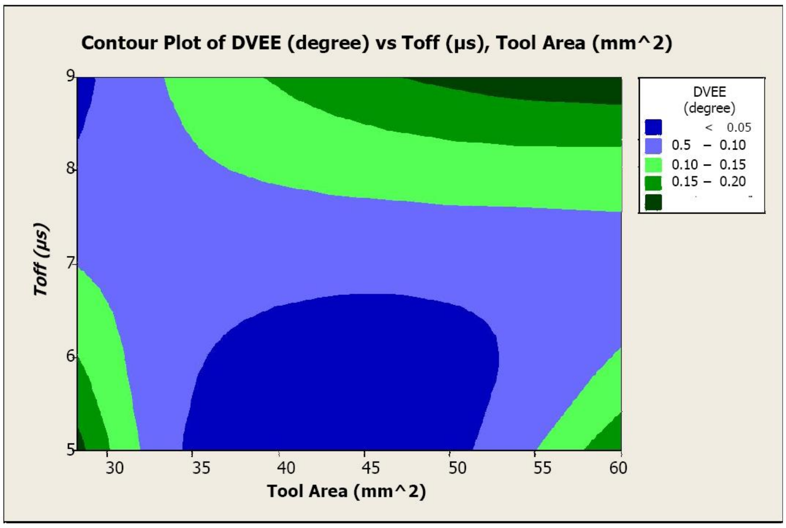

Fig. 18 Contour plot of DVEE vs Pulse-off time,Tool geometry

There are two regions in this contour plot where the tool wear rate is minimum when (i) the value of pulse off time lies between 8.5µs to 9.0µs while the tool area lies between 27.0 mm^2 to 29.0 mm^2 (ii) the value of pulse off time lies between 5.0µs to 6.5µs while the tool area lies between 34.0 mm^{2}to 53.0 mm^2.It is also inferred that the it is not advisable to have (i) the value of pulse off time in between 5.0µs to 5.1µs while the tool area lies in between 27.0 mm^2 to 28.0 mm^2 (ii) the value of pulse off time lies between 8.6µs to 9.0µs while the tool area lies between 46.0 mm^2 to 60.0 mm^2 because the DVEE is maximum at this range.

VI. GREY ANALYSIS FINDINGS

Grey Analysis has been used to find the optimal parameters for the EDM process with Material Removal Rate (MRR), Tool Wear Rate (TWR), and Deviation from Entrance to Exit (DVEE) as independent variables and Pulse-On Time, Pulse-Off time, Current and Tool Area as the dependent variables.

Table 4 Average Grey Relational Grades

LEVEL	FACTOR			
	A	B	C	D
1	0.564298	**0.636104**	**0.666774**	0.597707
2	0.634122	0.627502	0.621285	**0.6691**
3	**0.666765**	0.601579	0.577126	0.598377

Table 5 Optimized Parameters Corresponding to Grey Relational Grades

LEVEL	FACTOR			
	T_{ON}	T_{OFF}	CURRENT	TOOL AREA
1	19	**5**	**8**	28.27
2	29	7	11	**36**
3	**38**	9	14	60

The values having a bold front correspond to the optimal process parameters. They are listed below.
Pulse-On Time = 38 µs
Pulse-Off Time = 5 µs
Current = 8 amp
Tool Area = 36 mm^2

VII. CONCLUSSION

Grey analysis is carried out to obtain the optimal values corresponding to the highest values of the factors arrived by appropriate calculations.The optimal settings of the levels of the factors can be inferred from the above table containing the average Grey Relational Grades, in which the values having a bold front correspond to the optimal process parameters.The mathematical models were developed to establish the relationships between the process parameters (current, pulse on time, pulse off time and tool geometry) and the responses (Material Removal Rate, Tool Wear Rate, Deviation from Entrance to Exit).The Tool area has a significant influence on the Material Removal Rate (MRR) whereas the Current, Pulse-On Time, Pulse-Off Time and the Current do not contribute significantly to the Material Removal Rate (MRR).

The Pulse-On Time and Tool Area contribute significantly to the Tool Wear Rate whereas the Pulse Off and the Current contribute to a lesser extent.The Deviation from Entrance to Exit (DVEE) is influenced significantly by the Pulse-Off Time and the Tool Area. The Pulse-On Time and Current have very little influence on the Deviation from Entrance to Exit (DVEE).

Thus the relationship between the various process parameters and their responses has been determined. The optimal parameters have also been identified and determined by using the Grey Analysis Method.

REFERENCES

[1] Krar and Gill, The erosive effect of electrical discharges, pp 6.2.1.
[2] Lazarenko, B.R., To invert the effect of wear on electric power contact, Dissertation of the All-Union Institute for Electro Technique in Moscow/CCCP, Russian.
[3] Frans Van Dijck, Physico-mathematical analysis of the electro dicharge machining process, PhD Thesis Katholieke Universiteit te Leuven, 1973.
[4] Singh, A. & Ghosh A., A Thermo-Electric Model of Material Removal during Electric Discharge Machining. International Journal of Machine Tools Manufacture 39, pp 669-682 (1999).
[5] N. Mohri; M. Suzuki; M. Furuya & N. Saito (1995). Electrode wear process in electrical discharge machining, Ann. CIRP 44 (1), pp165-168.
[6] Marafona J and Wykes C, A new method of optimizing material removal rate using EDM with copper-tungsten electrodes, Int J Mach Tools Manuf 40(2): pg 153-164.
[7] Weng, C. C., T, "Effect of Residual stresses on Cold-Formed Steel Column Strength" A Companion Paper submitted to the ASCE Journal of the Structural Division, 1988.
[8] Sundaram MM, Pavalarajan GB and Rajurkar KP, A study on process parameters of ultrasonic assisted micro EDM based on Taguchi method, J Mater Engg Perf., pp 166-167.
[9] Yu Z, Masuzawa T and Fujino M, Micro-EDM for 3D cavities development of uniform wear method, ANN. CIRP 47 (1) (1998), pg 169-172.
[10] Ishida and Takeuchi, U-shaped Curved Hole Creation by Means of Electrical Discharge Machining, Springer US, pp 214-218.
[11] Muller and Monaghan, Non-Conventional machining of particles reinforced metal matrix composites, International Journal of Machine Tool Manufacturing, pp 1351-1366.
[12] Konig W, Dauw DF, Levy G and Panten U, EDM-future steps towards the machining of ceramics, Ann.

CIRP 37 (2) (1988) Pg 623-631
[13] Patel MR, Barrufet MA, Eubank PT and Dabitonto , Theoretical models of the electrical discharge machining process II, The anode erosion model: J applied Physics 66(9) pg 4095-4103
[14] Lee LC, Lim LC, Wong YS and Lu HH, Towards a better understanding of the surface features of eletro-discharge machined tool steels, J Mater Process Technol 24(C) pg 513-523
[15] Tsai KM and Wang PJ, Predictions on surface finish in electrical discharge machining based upon neural network models, Int J Mach Tools Manuf 41(10) pg 1385-1403.
[16] Lee SH and Li XP, Study of the surface integrity of the machined workpiece in EDM of tungsten carbide, J. Mater Process Technol 139: pg 315-321
[17] Tsai HC, Yan BH and Huang FY, EDM performance of Cr/Cu based composite electrodes, Int J Mach Tools Manuf 43(3): pg 245-252.
[18] Puertas I, Luis C and Villa G, Analysis of the influence of EDM parameters on surface quality, MRR, EW of WC-Co, J Mater Process Technol 164(165), pg 889-896.
[19] Ozgedik A and Cogun C, An experimental investigation of tool wear in EDM, Int J Adv Manuf Technol 27: pg 488-500.
[20] Jeong YH and Min B, Geometry prediction of EDM-drilled holes and tool electrode shapes of micro-EDM process using simulation, Int J Mach Tools Manuf 47(12-13), pg 1817-1826
[21] Khanra AK, Sarkar BR, Bhattacharya B, Pathak LC and Godkhindi MM, Performance of ZrB2-Cu composite as an EDM electrode, J Mater Process Technol 183, pg 122-126.
[22] Kumar PD, Study of thermal stresses induced surface damage under growing plasma channel in electro-discharge machining, J Mater Process Technol 202(1), pg 86-95.
[23] Sundaram MM, Pavalarajan GB and Rajurkar KP, A study on process parameters of ultrasonic assisted micro EDM based on Taguchi method, J Mater Engg Perf.
[24] Pellicer N, Ciurana J and Ozel T, Influence of process parameters and electrode geometry on feature micro-accuracy in electro-discharge machining of tool steel, Mater Manuf Process 24 pp pg1282-1289.