Electro Discharge Drilling (EDD) of Rice Husk Ash Reinforced Aluminium Matrix Composite Using Different Electrode Shapes

Partha Sarathi Mallick[1] and Shankar Singh[2]

[12]*Department of Mechanical Engineering Sant Longowal Institute of Engg. & Tech.*

Longowal- 148106 (Punjab)

Abstract

Electro discharge drilling (EDD) is a non-contact machining process which capable of producing holes of high aspect ratio, thus improving overall productivity and reducing the cycle time. It is a hybrid machining process which combines electric discharge machining (EDM) and drilling of electrically conducting hard materials..In the present study rice husk ash (RHA) particles have been incarnated in aluminium metal matrix by stir casting process. The RHA reinforced in aluminium matrix increases the mechanical properties and decrease the density of the composite material. This study investigates machinability of AA6063/ 5% RHA metal matrix composite using modified EDD set up with the help of Taguchi's Design of Experiments (DoE) methodology. L18 orthogonal array is used in Taguchi optimization technique. The process parameters that have been considered as control factors are peak current, pulse ON time, gap voltage and electrode rotation. Electrode tool geometry with conical and circular shape has been considered as noise factor. The performance measures that have been selected are material removal rate (MRR), tool wear rate (TWR) and diametric overcut (DOC). The main aim of the present study is to investigate the effect of the tool electrode geometry and rotation of tool electrode on the performance measures. It has been analyzed that electrode tool geometry plays major role in the increase of material removal rate (MRR) followed by electrode tool rotation, peak current, pulse on time and gap voltage High improvement in material removal rate has been observed due to effective flushing capability due to rotary effect of electrode. TWR decreases in an inverse relation with pulse on time. Peak current has high significant role on DOC because with increase in peak current DOC also get increases. Furthermore, conical shape tool electrode most prominently affects the MRR and TWR amongst all of the parameters.

Keywords

RHA reinforcement metal matrix composites, Electric discharge drilling, tool electrode geometry, performance measures, Taguchi's methodology

1 INTRODUCTION

In few decades, research has shifted from monolithic materials to composite materials to accomplish the global demand for light weight, high performance, environmental friendly and corrosion resistant materials. Driving force for the utilization of Aluminium metal matrix composites (AMMCs) in automotive, aerospace and military industries that include performance, economic and environmental benefits due to their high strength to wear ratio, stiffness, light weight, good wear resistance and improved thermal and electrical properties.[1]

Electro discharge drilling (EDD) is a thermal energy based hybrid nonconventional machining process that precisely controls sparks falling between the electrode and electrical conductive work piece causing the removal of material [2]. The application of EDD process is gaining tremendously due to its highly attractive properties like various hardness, strength and temperature resistance, complex shapes and accurate dimensions [3]. As EDD is cost- effective and time saving process compared to other mechanical machining, efforts have been made to fabricate electrically conductive composite over the years. Researchers have highly investigated on various aspects of EDD process [4]

The microstructure and mechanical properties of the fabricated composites of Rice Husk Ash (RHA) of three different particle size ranges (50-75μm), (75-100μm) and (100-150μm) in 3,6,9 and 12% by weight was reinforced with the aluminium alloy results that the tensile strength, compressive strength and hardness of the aluminium alloy composites decrease with increase in particle size of RHA[5]. RHA particle neither decompose nor interact with aluminium to form any sort of intermetallic compounds. The higher the content of RHA particle, the more the grain nucleation sites are created as well as the more the resistance is offered to the freely growing α (Al) grains [6]. It has been analyzed that centrifugal force created due to rotation of electrode remove debris from the machined work piece along with injection flushing results high MRR and TWR [7]. . This paper suggested that drilling series of blind holes with minimum relative error with respect to the intended depth could be possible. Investigation suggest that tool wear length get eroded due to which the total tool travel distance must be greater than the sum of intended depth and the tool wear length[8] The current strategy updated the part program automatically after each drilling which results in the reduction of total ideal time associated with offline tool compensation method[9]. On investigation EDD of small holes in Inconel 718 by varying electrode size and geometry researcher analyzed that if pulse energy is below threshold value of about 7 to 10 mJ then there is abrupt change in drilling speed and MRR decreases by five times[10]. The study reveals that surface roughness and overcut increases with an increase in voltage, frequency as well as duty factor [11]. It has been studied EDD of SiC reinforced polymer matrix composite by using GRA to optimize the process parameter so as to have optimum MRR and radial overcut and noticed while performing experiment that overcut is higher because of the presence of abrasive particles. With increase in voltage, MRR increases as well as diametric overcut also increases [12].

2 Experimental procedure

Experimentation has been performed on Aluminium matrix composite, whose base material is Aluminium Alloy 6063 and T6 is temper designation. Stir Casting is a liquid state method which is used for fabrication of composite materials, in which a dispersed phase (RHA particles) is mixed with a molten matrix metal by means of mechanical stirring. The apparatus uses a motor for stirring the matrix-reinforcement melt, with variable speed controller. 1 wt% of magnesium is added into molten melt to enhance wettability. The predesigned EDD set up before manufacturing and assembly is shown in figure 1.

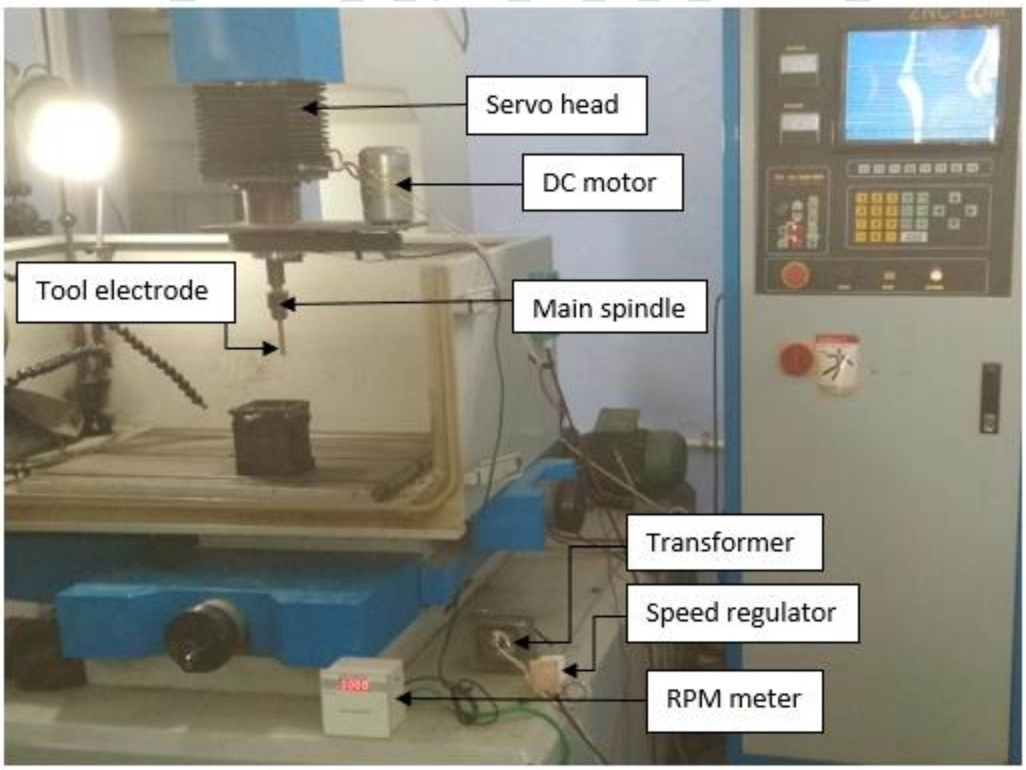


Figure 1. EDD set up fitted on EDM (E-ZNC)

Experiments has been performed on Sparkonix S-50 model EDM machine. With the help of servomotor Z- axis is controlled while x-axis and y-axis movements are given to the work-table manually. The drilling process setup has been designed while keeping in mind weight and cost economical but fulfills logical requirements of various parts. Mounting plate of EDD set up is attached with the servo head of the electro discharge machine by means of bolts.

Geometry of the electrode is designed on the basis of research theory and comparative study is done to find its effect on process performance measures. The study has high significant role to specify its application in order to establish strong guidelines for desired output (response). The selected work material in the present study is Rice Husk Ash reinforced Aluminium matrix composite with thickness of 10mm. Blind holes upto 4mm were drilled in the specimen.

Table 1 describes the process parameters used during experimentation. Change in electrode geometry, initial and final weight of the work piece, electrode and elapsed time were recorded after each drilling cycle.

Table 1. Process parameters used during experimentation

S. No	Process Parameters	Symbol	Unit	Levels		
				1	2	3
1	**Noise Factor**					
	Tool Electrode Geometry			Circular	Conical	
2	**Control Factors**					
	Peak current	I_p	A	9	12	15
	Pulse on time	Ton	µs	60	90	120
	Gap voltage	V_g	V	40	45	50
	Rotational speed of electrode	Ne	rpm	200	400	600

4 Results and discussion

MRR, TWR and DOC has been considered as essential response variable that has direct influence on process parameter. The major objective in the present study is to study the effect of different electrode geometry on the performance measures during EDD of composite material and establish optimum electrode geometry at optimum process parameter to obtain maximum MRR, low TWR and low DOC. The basic attractive phenomenon of the EDD process is its exclusive nature of material removal rate from electrode, tool rotation and easy flow of debris between electrode gap as shown in fig 2.

In the present study material removal rate from RHA reinforced Aluminium matrix composite of negative polarity is much higher than tool electrode of positive polarity. Tool wear and Diametric overcut are inheritable characteristics that could not be avoided but minimized to optimum level. The volume wear of electrode with high degree of accuracy could be accomplish by experimental measurement which is necessary to measure tool wear rate.

3.1 Effect of process parameters on MRR

The optimal machining performance for MRR has been obtained at electrode tool geometry (Conical), Peak current (15A), Pulse ON time (90µs), gap voltage (50V), and electrode rotational speed (400 rpm).
Conical electrode tool geometry gives high material removal rate (MRR) than circular electrode tool geometry as current density increases with decrease in total contact area while machining of work material.

Current density = $\frac{\text{Current}}{\text{Surface area in contact}} = \frac{I}{A}$

Circular electrode: Total contact surface area = $\pi r^2 + 2\pi rh$

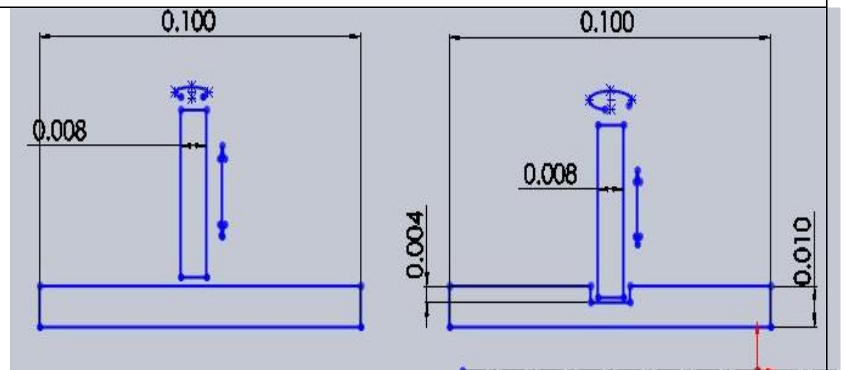
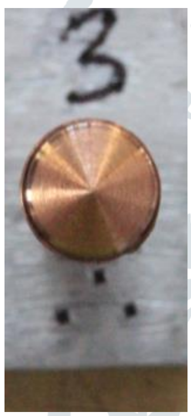
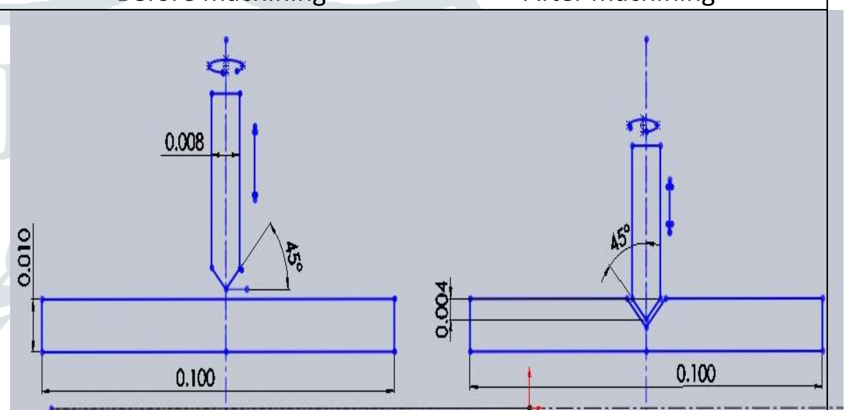
Tool electrode	Tool geometry	View of tool point	Region
a. Solid cylindrical			 Before machining After machining
b.Conical			 Before machining After machining

Fig 2. Tool geometry of the various copper tool electrode

$= (3.14*4^2 + 2*3.14*4*4) = 150.7\ mm^2$ (r= 4mm and h= 4mm)

Where r is electrode radius and h is contact length.

Conical electrode: Total contact surface area = πrl

or, $l = (r^2+h^2)^{1/2} = l=(4^2+4^2)^{1/2} = 5.656$

or, $= \pi rl = (3.14*4*5.656)= 71.050mm^2$ (r=4mm and h= 4mm)

where r is electrode radius, h is contact length and l is slant height.

Electrode rotation increases MRR from 200rpm to 400rpm due to proper flushing and easily removal of debris but with further increase in rpm concentration of the electrode on hole fluctuates which results decrease of MRR.
Since P- value for factors electrode geometry, peak current electrode rotation and interaction between electrode rotation and electrode geometry in less than 0.5, shown in Table 2; which implies that all factors and interaction are significant at confidence level of 95%.

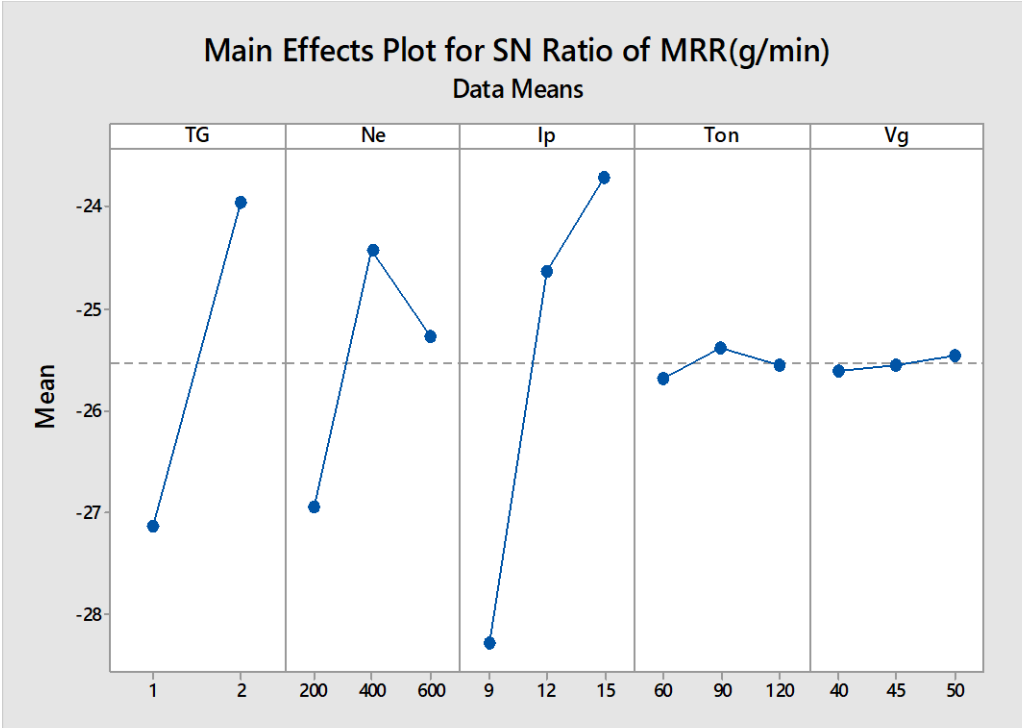


Fig 3 Main effects plot for S/N Ratios

Table 2 Analysis of Variance of S/N Ratio for MRR

Source	**No. of Levels**	**DF**	**SS**	**MS**	**F-value**	**P-value**
Electrode geometry	2	1	46.072	46.0724	240.63	0.000
Electrode Rotation(rpm)	3	2	20.034	10.0170	52.32	0.000
Peak Current I_p(A)	3	2	70.628	35.3139	184.44	0.000
Pulse ON time (μs)	3	2	0.260	0.1302	0.68	0.542
Gap voltage V_g (V)	3	2	.061	0.0303	0.16	0.857
Electrode tool geometry*Electrode tool rotation (RPM)		2	10.175	5.0875	26.57	0.001
Residual error		6	1.149	0.1915		
Total	14	17	148.379			

3.2 Effect of process parameter on TWR

The optimal machining performance for TWR has been obtained at electrode tool geometry (circular), Peak Current (9A), Pulse ON time (90μs), Gap Voltage (45V), and Electrode Rotation (400rpm).TWR is less while working with Peak current of 9A and circular geometry electrode. Due to increase in spark energy, temperature on machining zone increases which decomposes the dielectric contaminants into carbon atoms which get attached to the tool surface. Carbon layer on tool surface reduces the conductivity of tool which results decrease of tool wear rate. But electrode rotation throw this contaminants in the dielectric which is more in case of conical electrode resulting high tool wear rate. Since P-value for electrode tool geometry, Pulse ON time and electrode rotation are less than 0.05; which implies that factor electrode tool geometry, Pulse ON time and electrode rotation are significant at confidence level of 95%.

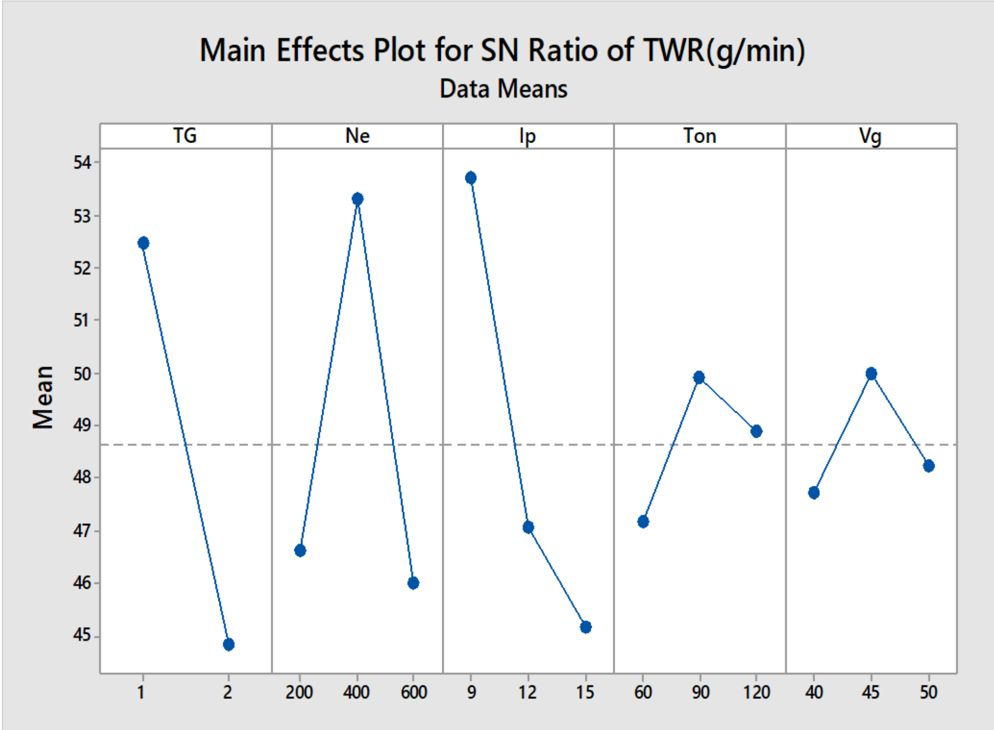


Fig 4 Main Effects plot for S/N Ratios for TWR

Table 3 Analysis of Variance for S/N Ratio for TWR

Source	**No. of levels**	**DF**	**SS**	**MS**	**F-value**	**P-value**
Electrode Tool Geometry	2	1	264.23	264.225	150.35	0.000
Electrode rotation (rpm)	3	2	197.64	98.820	56.23	0.000
Peak Current I_P (A)	3	2	243.96	121.980	69.41	0.000
Pulse ON time (µs)	3	2	23.18	11.590	6.60	0.031
Gap Voltage V_g (V)	3	2	17.10	8.551	4.87	0.055
Electrode tool geometry*Electrode tool rotation (RPM)		2	20.88	10.440	5.94	0.038
Residual Error		6	10.54	1.757		
Total	14	17	777.53			

3.3 Effect of process parameter on DOC

The optimal machining performance for DOC has been obtained at electrode tool geometry (Conical), Peak current (9A), pulse ON time (60µs), gap voltage (50V) and electrode rotation (400rpm). When electrode rotation increases from 200 to 400 rpm, DOC decreases but with further increase in speed DOC increases. It may be due to more vibration of the tool electrode resulting less pointed concentration. DOC can be optimized by controlling the other process parameter such as peak current, pulse ON time, gap voltage and tool geometry. Conical geometry tool electrode shows less DOC as compared to Circular geometry tool electrode. This may be due to high value of thermal energy transfer to machining zone. With increase in peak current more current density develops which results increase in DOC.

Since P-value for Peak current, electrode geometry and electrode rotation are less than0.05; it implies that this are the only factor which are significant at confidence level of 95%.

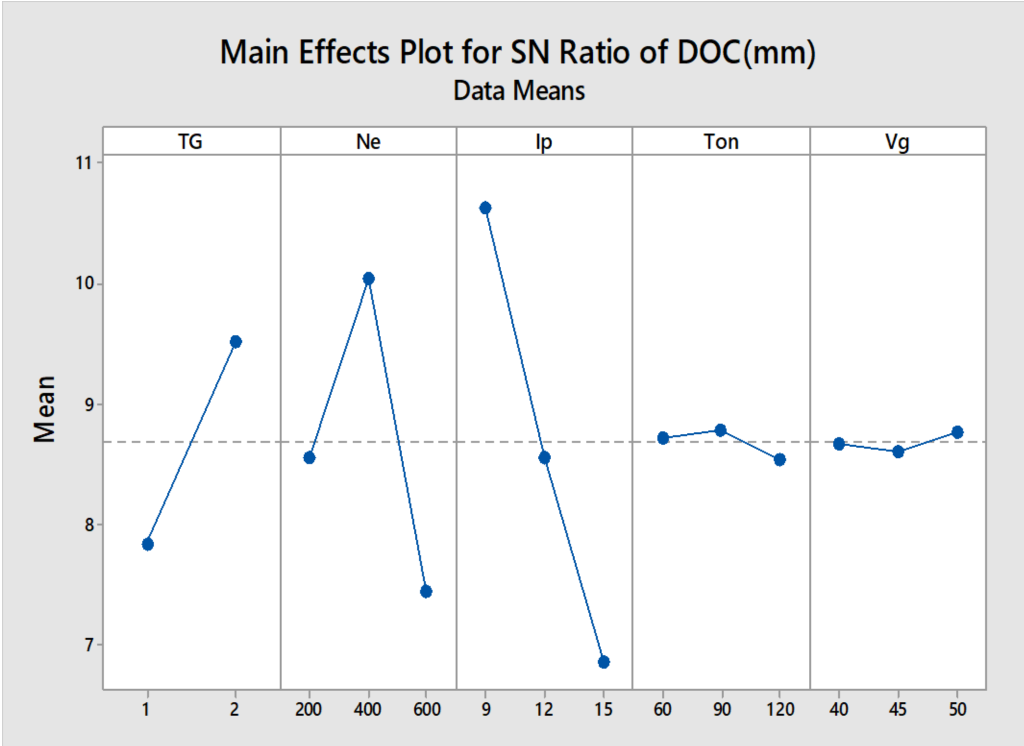


Fig 5 Main Effects plot for S/N Ratios for DOC

Table 4 Analysis of Variance for S/N Ratio for DOC

Source	No. of levels	DF	SS	MS	F-value	P-value
Electrode tool geometry	2	1	12.7995	12.7995	115.93	0.000
Electrode Rotation (rpm)	3	2	20.2024	10.2024	92.41	0.000
Peak Current I_p (A)	3	2	43.2606	21.6303	195.92	0.000
Pulse ON time (µs)	3	2	0.2143	0.1072	.097	0.431
Gap Voltage V_g (V)	3	2	0.0720	0.0360	0.33	0.734
Electrode tool geometry* Electrode Rotation		2	6.6859	3.3429	30.28	0.001
Residual Error		6	0.6624	0.1104		
Total	14	17	84.0994			

5 Conclusion

1. EDD is suitable alternative hybrid process for making holes in extreme hard materials such as Composites.

2. Geometry of the tool electrode acts as major factor in defining the process performance of the EDD process in terms of MRR, TWR and DOC.

3. The surface area in contact between the tool electrode and the work piece plays high significant role on MRR, TWR and DOC.

4. Conical geometry tool electrode gives high MRR, high TWR and low DOC as compared to circular geometry tool electrode.

5. Optimum parametric setting for higher MRR is A2 (Conical geometry copper electrode), B2 (400 rpm electrode rotation), C3 (15A peak current), D2 (90 µs pulse 0N time) and E3 (50V gap voltage).

6. Optimum parametric settings for minimum TWR is A1 (Circular geometry tool electrode), B1 (200rpm electrode rotation), C2 (12A peak current), D3 (120 µs pulse ON time) and E3 (50V gap voltage).

7. Optimum parametric settings for low DOC is A1 (Conical geometry tool electrode), B2 (400rpm electrode rotation), C1 (9A peak current), D1 (60 µs pulse ON time) and E3 (50V gap voltage).

8. High improvement in material removal rate has been observed due to effective flushing capability which becomes possible due to rotary effect of electrode. However, the large rotational speed can also reduce the machining performance. Maximum MRR and low TWR has been achieved at 400 rpm of electrode rotation.

9. Impending need of optimum process performance compel to improve the EDD process and the present research highly initiate in this direction. In further study, experimental investigation may be carried out on various optimization technique to establish high quality process performance in hard to machine materials such as MMCs.

6 References

1. Singh, S., Maheshwari, S. and Pandey, P.C., 2007. Optimisation of multiperformance characteristics in electric discharge machining of aluminium matrix composites (AMCs) using Taguchi DOE methodology. *International journal of manufacturing research*, *2*(2), pp.138-161.

2. Gourgouletis, K., Vaxevanidis, N.M., Galanis, N.I. and Manolakos, D.E., 2011. Electrical discharge drilling of carbon fibre reinforced composite materials. *International Journal of Machining and Machinability of Materials*, *10*(3), pp.187-201.

3. Song, K.Y., Park, M.S. and Chu, C.N., 2009. Micro electrical discharge drilling of tungsten carbide using deionized water. *Journal of Micromechanics and Microengineering*, *19*(4), p.045006.

4. Mohan, B., Rajadurai, A. and Satyanarayana, K.G., 2004. Electric discharge machining of Al–SiC metal matrix composites using rotary tube electrode. *Journal of materials processing technology*, *153*, pp.978-985.

5. Saravanan, S.D. and Kumar, M.S., 2013. Effect of mechanical properties on rice husk ash reinforced aluminum alloy (AlSi10Mg) matrix composites. *Procedia Engineering*, *64*, pp.1505-1513.

6. Gladston, J.A.K., Sheriff, N.M., Dinaharan, I. and Selvam, J.D.R., 2015. Production and characterization of rich husk ash particulate reinforced AA6061 aluminum alloy composites by compocasting. *Transactions of Nonferrous Metals Society of China*, *25*(3), pp.683-691.

8. Wang, C.C. and Yan, B.H., 2000. Blind-hole drilling of Al_2O_3/6061Al composite using rotary electro-discharge machining. *Journal of materials processing technology*, *102*(1-3), pp.90-102.

9. Soni, J.S. and Chakraverti, G., 1994. Machining characteristics of titanium with rotary electro-discharge machining. *Wear*, *171*(1-2), pp.51-58.

7. Singh, S. and Pandey, A., 2013. Some Studies into Electrical Discharge Machining of Nimonic75 Super Alloy Using Rotary Copper Disk Electrode. *Journal of materials engineering and performance*, *22*(5), pp.1290-1303.

10. Singh, A., Kumar, P. and Singh, I., 2013. Process optimization for electro-discharge Drilling of Metal Matrix Composites. *Procedia Engineering*, *64*, pp.1157-1165.

11. Bassoli, E., Denti, L., Gatto, A. and Iuliano, L., 2016. Influence of electrode size and geometry in electro-discharge drilling of Inconel 718. *The International Journal of Advanced Manufacturing Technology*, *86*(5-8), pp.2329-2337.

12. Antil, P., Singh, S. and Manna, A., 2018. Electrochemical discharge drilling of SiC reinforced polymer matrix composite using Taguchi's grey relational analysis. *Arabian journal for Science and Engineering*, *43*(3), pp.1257-1266.