Experimental Investigation of Machine parameters For EDM Using U shaped electrode of EN-19 tool steel

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ABSTRACT

In this paper, an attempt has been made to machining the En-19 tool steel by using U-shaped copper electrode performe on electrical discharge machine. Where Diameter of U-shaped electrode, Current and Pulse on time are taken as process input parameters and material removal rate, tool wear rate, Overcut on surface of work piece are taken as output parameters. A set of eighteen experiments(Taguchi design)were performed on electronica make smart ZNC electric discharge machine and relationships were developed between input and output parameters. The study indicates that, MRR increased with the discharge current (Ip). As the pulse duration extended, the MRR decreases monotonically. In the case of Tool wear rate the most important factor is discharge current then pulse on time and after that diameter of tool. In the case of over cut the most important factor of discharge current then diameter of the tool and no effect on pulse on time .

KEYWORDS - Electrical discharge machining (EDM), Material removal rate (MRR), Tool wear rate (TWR), Overcut (OC).

I. INTRODUCTION

It is clear that the past few years have seen an increasing interest in the novel applications of electrical discharge machining to see the potential of this technique for better process performances it is obvious that lot of work has been done to optimize the EDM process and the work related to finding the feasibility of harder material. The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Electrical Discharge Machining (EDM). It is a capable of machining geometrically complex or hard material components, that are precise and tool steels, composites, super alloys, ceramics, carbides, heat resistant steelspulse on time and diameter of tool of En-19 tool steel material. Using U-shaped cu tool with internal flushing. A well- designed experimental scheme was used to reduce the total number of experiments. Parts of the experiment were conducted with the L18 orthogonal array based on the Taguchi method . And non- conventional machining. The Electric discharge machining process is finding out the effect of machining parameter such as discharge current, materials, posses greater strength and toughness are usually known to create major challenges during conventional forming tools. These steel are categorized as difficult to machine rang of application in Plastic moulds, frames for plastic pressure dies, hydro better polishability, it has a grooving tempered condition. Good machinability, hardened and as preferred particle size, sintering temperatures and pressures. Despite the promising results, electric discharge and nuclear industries. En-19 Plastic mould steel that is usually supplied in a making industries, aerospace, aeronautics etc. being widely used in die and mold.

Past Work: Dhar and Purohit [1] evaluates the effect of effect of MRR, TWR, SR with Process parameters taken in to consideration were the current (I), the pulse duration (T) **Al–4Cu–6Si alloy–10 wt. % SiCp composites**. Karthikeyan et .al [2] has presented the mathematical molding of EDM with **aluminum-silicon carbide particulate composites**. Mathematical equation is Y=f(V, I, T). And the effect of MRR, TWR, SR with Process parameters taken in to consideration were the current (I), the pulse duration (T) and the percent volume fraction of SiC (25 µ size). B.Mohan and Satyanarayana [3] evolution the of effect of the EDM Current, electrode marital polarity, pulse duration and rotation of electrode on metal removal rate, TWR, and SR, and the EDM of **Al-Sic with 20-25 vol. % SiC**, Polarity of the electrode and volume present of SiC, the MRR increased with increased in discharge current and specific current it decreased with increasing in pulse duration. Increasing the speed of the rotation electrode resulted in a positive effect with MRR, TWR and better SR than stationary. The electric motor can be used to rotate the electrode(tool) AV belt was used to transmit the power from the motor to the electrode Optimization parameters for EDM drilling were also developed to summarize the effect of machining characteristic such as MRR, TWR and SR. Vijay Kumar, Naveen beri, Anil and paramjit singh [4] has made to study the process performance of electrical discharge machining with powder metallurgy tool electrode during the machining of hastelloy using positive polarity. Where current and voltage are taken as process input parameters and material removal rate ,tool wear rate, percentage wear rate, surface roughness are taken as output parameters. A set of ten experiments were performed on electronic make smart ZNC electric discharge machine and relationships were developed between input and output parameters. The study indicates that, the maximum material removal rate is at the average value of current and voltage with in the selected range of process input parameters, the minimum tool wear rate is with the minimum value of current and voltage, the minimum value of average surface roughness for average value of current and voltage . Hk Kansal, Sehijpal Singh and pardeep Kumar[5] has investigated the performance parameters optimization(multi-characteristics) of powder mixed electric discharge machining(PMEDM) throuth taguchi's method. Bing Hwa et al. [6] has discuss the investigates the feasibility and optimization of a rotary EDM with ball burnishing for inspecting the machinability of **Al_2O_3/6061Al composite** using the Taguchi method. Three ZrO_2 balls attached as additional components behind the electrode tool offer immediate burnishing following EDM. Three observed values machining rate, surface roughness and improvement of surface roughness are adopted to verify the optimization of the machining technique. Design of tool electrode is Cupper ring shaped B- EDM as shown in Fig 1(a). This B-EDM process approaches both a higher machining rate and a finer surface roughness. Furthermore, the B-EDM process can achieve an approximately constant machining rate.

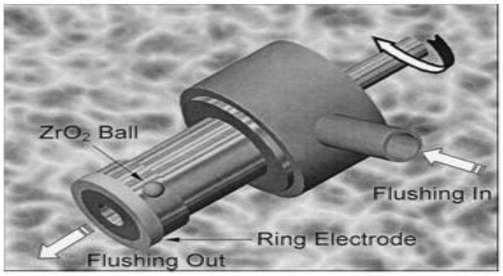


Figure 1(a)Design of Cu ring tool shaped B-EDM

Yan-Cherng Lin et al.[7] has reported that Electrical Discharge Energy on Machining of **Cemented Tungsten Carbide** using an electrolytic copper electrode. The machining parameters of EDM were varied to explore the effects of electrical discharge energy on the machining characteristics, such as MRR, EWR, and surface roughness. Moreover, the effects of the electrical discharge energy on heat-affected layers, surface cracks and machining debris were also determined. The experimental results show that the MRR increased with the density of the electrical discharge energy. The EWR and diameter of the machining debris were also related to the density of the electrical discharge energy. Puertas and Luis[8] has define the optimization of machining parameter for EDM of **Boron carbide** of conductive ceramic materials. It is these conditions that determine such important characteristics as surface roughness, electrode wear, and MRR. In this article, a review of the state of art of the die-sinking EDM processes for conductive ceramic materials, as well as a description of the equipment used for carrying out the experiments, are presented. Wang and Lin [9] discuss the optimization of W/Cu composite martial are used the Taguchi method. **W/Cu composites** are a type of cooling material highly resistant to heat corrosion produced through powder metallurgy. The Taguchi method and L18 orthogonal array to obtain the polarity, peak current, pulse duration, duty factor, rotary electrode rotational speed, and gap- load voltage in order to explore the material removal rate, electrode wear rate, and surface roughness. Tsai et al [9] have working martial of graphite, copper and copper alloys are widely using EDM because these materials have high melting temperature, and excellent electrical and thermal conductivity. The electrodes made by using powder metallurgy technology from special powders have been used to modify EDM surfaces in recent years, to improve wear and corrosion resistance. Saha and Choudhury [10] Study the process of dry EDM with **tubular** copper tool electrode and mild steel workpiece. Experiments have been conducted using air and study the effect of gap voltage discharge current, pulse-on time, duty factor, air pressure and spindle speed on MRR, surface roughness (Ra) and TWR. Empirical models for MRR, Ra and TWR have then been developed by performing a designed experiment based on the central composite design of experiments. Lin and Han [11] presented the study about **tube electrode** for an EDM drilling includes a stabilizer block and a mover. The stabilizer block has a concaved in shaped supporting wall that parallels to the traveling path of a tube electrode, and has a plurality of apertures interconnected to air vacuuming connections to suck air. The move is connected to the stabilizer block for approaching the tube electrode. Sohani et al. [12] discussed about sink EDM process effect of **tool shape and size factor** are to be considering in process by using RSM process parameters like discharge current, pulse on-time, pulse off-time, and tool area. The RSM-based mathematical models of MRR and TWR have been developed using the data obtained through central composite design. The analysis of variance was applied to verify the lack of fit and adequacy of the developed models. The investigations revealed that the best tool shape for higher MRR and lower TWR is circular, followed by triangular, rectangular, and square cross sections. Zhon and Han [13] worked on servo system for EDM, adaptive control of with self turning regulator a new EDM adaptive control system which directly and automatically regulates tool- down-time has been developed. Based on the real-time-estimated parameters of the EDM process model, by using minimum-variance control strategy, the process controller, a self-tuning regulator, was designed to control the machining process so that the gap states follow the specified gap state. The EDM process workpiece generated by the superposition of **multiple discharges**, as it happens during an actual EDM operation, by Izquierdo et al. [14] diameter of the discharge channel and material removal efficiency can be estimated using inverse identification from the results of the numerical model. An original numerical model for simulation of the EDM process has been presented. Wei Bin et al. [15] has study about electrical discharge machining with multiple holes in an electrically conductive work piece, includes an electrical discharge machine for rotatable mounting a first electrode, and at least one electrical discharge unit for rotatable mounting at least one second electrode. The electrical discharge machine includes a driver and a controller, the driver is desirably coupled to the electrical discharge machine and the electrical discharge unit for rotating the first electrode and the at least one second electrode, and the controller is desirably coupled to the electrical discharge machine and the at least one electrical discharge unit for controlling a supply of electrical energy from the first electrode and second electrode to the workpiece. Kunge et al. [16] evolution the effect of MRR and EWR study on the powder mixed electrical discharge machining (PMEDM) of cobalt-bonded tungsten carbide (WC-Co) has been carried out. In the PMEDM process, the aluminum powder particle suspended in the dielectric fluid disperses and makes the discharging energy dispersion uniform; it displays multiple discharging effects within a single input pulse. This study was made only for the finishing stages and has been carried out taking into account the four processing parameters: discharge current, pulse on time, grain size, and concentration of aluminum powder particle for the machinability evaluation of MRR and EWR. Ding and Jiang [17] presented the work on CNC EDM machining of free-form surfaces requires tool paths that are different from those used in mechanical milling although in geometry both processes are described by the similar model of intersection between the rotating tool and the

Workpiece. Special requirements on tool paths demanded by CNC EDM machining are studied and a two-phase tool path generation method for 4-axis CNC EDM rough milling with a cylindrical electrode is developed. Bleys et al. [18] has discuss about CNC contouring EDM with a rotating cylinder and or tubular electrode necessitates compensation of the tool electrode wear in CNC milling operation is based on off-line tool wear simulation prior to machining.

II. Objective of the present work-

1. To find feasibility of machining EN-19 tool steel using U-shaped tubular copper electrode and internal flushing.
2. To analyze the responses MRR, TWR, and over cut by using the machining parameter selected for discharge current, pulse on time, and diameter of the tool using Taguchi design approach.
3. To Find the influence of MRR With discharge current, pulse duration time, and diameter of the tool.
4. To find the influence tool wear rate with discharge current, pulse on time and diameter of tool.
5. To find the influence on over cut with discharge current, diameter of the tool and, pulse on time.
6. To investigate the machining parameters for EDM using shaped electrode of EN-19 tool steel.

III. Experimental work

The experimental work which is consist about formation of the L-18 orthogonal array based on Taguchi design, orthogonal array is reduces the total on of experiment, in this experiment total 18 run. And Experimental set up, selection of workpiece, tool design, and taking all the value and calculation of MRR, TWR, and OC.

Experimental set up

For this experiment the whole work can be down by Electric Discharge Machine, model ELECTRONICA- ELECTRAPULS PS 50ZNC (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric fluid. With internal flushing of U-shaped cu tool with a pressure of 0.2 kgf/cm .Experiments were conducted with positive polarity of electrode. The pulsed discharge current was applied in various steps in positive mode.

Step No.1 Selection of workpiece

EN-19 tool steel is very hard having the following Mechanical properties.

Mechanical properties of EN-19 steel

Properties	
Tensile strength	1150N/mm2
Yield stress	850N/mm2
Elongation	14-17%
Modulus of	210000N/mm2
Density	7.8Kg/m3
Hardness	55 HRC

This is very hard material so it is not feasible to machine it by both conventional and non conventional machining processes. In non conventional machining if we select some parameters like current, pulse on time and diameter then it makes feasible to machining the material.

Step No.2 Selection of tool

U shaped cooper tool with internal flushing is used.Why U shaped tool is used: because we want U shaped cavity in the workpiece having diameter greater than the tool diameter.

Step No.3 Machining Parameters

1. Diameter of tool(D)
2. Pulse duration time(Ton)
3. Discharge current

Step No.4 Calculations for M.R.R , T.W.R and overcut OC

1. Evaluation of MRR-

The material MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time and density of the material.

$$MRR = \frac{Wjb - Wja}{t \times p}$$

Wjb = Weight of workpiece before machining.

Wja = Weight of workpiece after machining.

t = Machining time = 1.00 hr.

p = Density of EN-19 steel material =7.84gm/cm^3

2. Evaluation of tool wear rate

TWR is expressed as the ratio of the difference of weight of the tool before and after machining to the machining time. That can be explain this equations

$$TWR = \frac{Wtb - Wta}{t}$$

Whereas

Wtb = Weight of the tool before machining.

Wta = Weight of the tool after machining.

t = Machining time (In this experiment the machining time is one hour).

3. Evaluation of over cut

OC is expressed as half the difference of diameter of the hole produced to the tool diameter that is shown in these equations.

$$OC = \frac{Djt - Dt}{2}$$

Djt= diameter of hole produced in the workpiece

Dt= diameter of tool

Machining parameters and their level

Machining parameter	Symbol	Unit	Level		
			Level1	Level2	Level3
Electrode diameter	(D)	mm	6	8	
Spark on time	(Ton)	μs	5	50	1000
Discharge current	(Ip)		1	3	5

IV.Conduct of Experiment –

EN-19 Tool steel material particulate was using U-shaped Copper tube tool with 6 mm and 8 mm diameter. And the PS 50ZNC (die-sinking type) of EDM machine are used. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric fluid. Internal flushing with U-shaped copper tool with internal flushing was used to flush away the eroded materials from the sparking zone. In this experiment voltage and duty cycle is kept constant is 50 v and 8. For a three factor are tackled with a total number of 18 experiments performed on die sinking EDM. The calculation of material removal rate and tool wear rate by using electronic balance weight machine. This machine capacity is 300 gram and accuracy is 0.001 gram. And the over cut measurement can be using tool maker microscope this machine accuracy is 0.0001 mm.

Observation Table

Run	Dia (mm)	Ip (A)	Ton (μs)	Wt of Workpiece (gm)		Wt. of Tool (gm)		Cavity dia. (mm)
				Wjb	Wja	Wtb	Wta	Djt
1	6	1	50	270.430	270.113	20.784	20.781	7.845
2	6	1	500	270.113	269.98	20.781	20.777	7.908
3	6	1	1000	269.980	269.970	20.777	20.776	7.736
4	6	3	50	269.970	267.917	20.776	20.736	7.838
5	6	3	500	267.917	267.421	20.736	20.710	7.900
6	6	3	1000	267.421	267.315	20.710	20.708	7.720
7	6	5	50	267.315	265.325	20.708	20.611	7.864
8	6	5	500	263.319	261.754	20.611	20.503	7.842
9	6	5	1000	261.754	261.634	20.539	20.528	7.958
10	8	1	50	261.634	261.343	22.579	22.564	8.163
11	8	1	500	260.473	260.268	22.564	22.543	8.156
12	8	1	1000	260.268	260.241	22.543	22.542	8.081
13	8	3	50	260.241	258.120	22.542	22.539	8.140
14	8	3	500	257.236	256.759	22.539	22.533	8.102
15	8	3	1000	256.075	255.937	22.533	22.510	8.072
16	8	5	50	254.437	252.446	22.510	22.498	8.191
17	8	5	500	252.446	251.725	22.498	22.473	8.143
18	8	5	1000	251.725	251.524	22.473	22.470	8.094

Experiments were conducted according to Taguchi method by using the machining set up and the designed U-shaped tubular electrodes with internal flushing. The control parameters like diameter of electrode (D) , discharge current (Ip) and pulse duration (Ton) conductivity were varied to conduct 18 different experiments and the weights of the work piece and Tool and dimensional measurements of the cavity were taken for calculation of MRR , TWR and over cuts.

Response table –

The response table for MRR, TWR and OC are shown in Table along with the input factors.

Response Table

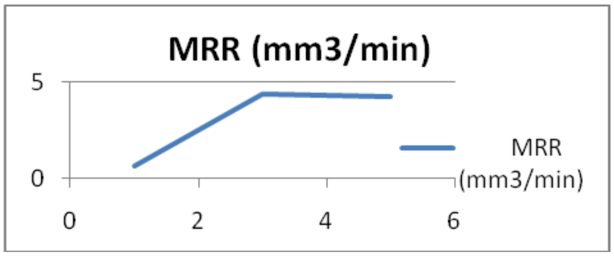
Run	Dia (mm)	Ip (A)	Ton (μs)	MRR (mm^3/min)	TWR (gm/min)	OC (mm)
1	6	1	50	0.673	0.00005	0.922
2	6	1	500	0.282	0.00006	0.908
3	6	1	1000	0.021	0.00001	0.868
4	6	3	50	4.364	0.00001	0.919
5	6	3	500	0.496	0.00043	0.950
6	6	3	1000	0.223	0.00003	0.860
7	6	5	50	4.230	0.00161	0.932
8	6	5	500	3.326	0.00180	0.921
9	6	5	1000	0.255	0.00018	0.974
10	8	1	50	0.618	0.00025	0.081
11	8	1	500	0.435	0.00035	0.078
12	8	1	1000	0.057	0.00001	0.040
13	8	3	50	4.508	0.00005	0.070
14	8	3	500	1.014	0.00012	0.077
15	8	3	1000	0.293	0.00038	0.036
16	8	5	50	4.232	0.00026	0.095
17	8	5	500	1.532	0.00048	0.082
18	8	5	1000	0.427	0.00005	0.047

In the present study on the effect of machining responses are MRR, TWR and OC of the EN-19 plastic mould steel component using the U-Shaped cu tool with internal flushing system tool have been investigated for EDM process. The experiments were conducted under various parameters setting of Discharge Current (Ip), Pulse On-Time (Ton), and diameter of the tool. L-18 OA based on Taguchi design was performed for Minitab software was used for analysis the result and these responses were partially validated experimentally.

V. Analysis of Material Removal Rate

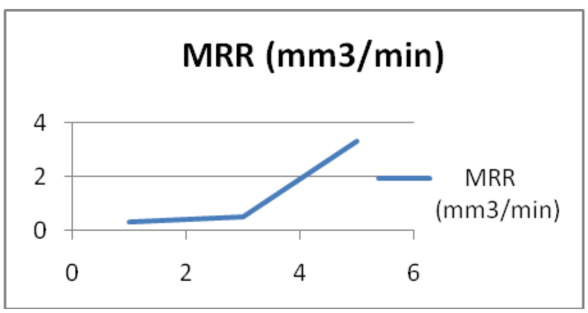
Current

As shown in graph1(a) that as the current increases MRR improves up to 3 amperes and then decreases. Pulse on time (Ton) is 50 µs. This can be explained as initially with increase in current MRR increases because of higher erosion of work piece material with increase in current. Thereafter with future increase in current net deposition on work piece material from metallurgical tool electrode take place. This explains the decrease in MRR. The MRR is 4.364 mm3/min.



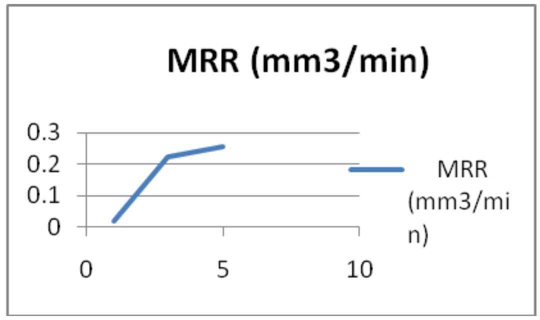
Graph.1(a) Line chart for MMR with current Ip
(pulse on for 50 µs)

As shown in graph1(b) when the pulse on is kept 500 µs as the current is increases there is slowly improvement in MRR and after then increases faster this is because as the MRR is decreases with increase in pulse on time. In graph (a) see carefully the value of MRR is more than the value of MRR in graph (b).



Graph1(b) Line chart for MMR with current Ip
(pulse on for 500 µs)

In graph1(c) MRR is increases with current but at current 3A the MRR is decreases . This is due to the net deposition on workpiece material from metallurgy tool electrode. Pulse duration is 1000 µ s.



Graph1(c) Line chart for MMR with current Ip
(pulse on for 1000 µs)

VI. Analysis of Tool Wear Rate

Current

Increasing in the discharge current from 1 to 3 A the tool wear rate is decreasing, but discharge Current in the range of 3 to 5 A the tool wear rate is increasing. Because of Ip increases the pulse energy increases and thus more heat energy is produced in the tool work piece interface, leads to increase the melting and evaporation of the electrode. One can interpret that Ip has a significant direct impact on TWR By **Dhar and Purohit** . And pulse on time is directly proportional to the tool wear rate. And diameter of the tool has no significant effect on TWR. The interaction plot of TWR is shown in Fig 2(a). And pulse on time is directly proportional to the tool wear rate. And diameter of the tool has no significant effect on TWR.

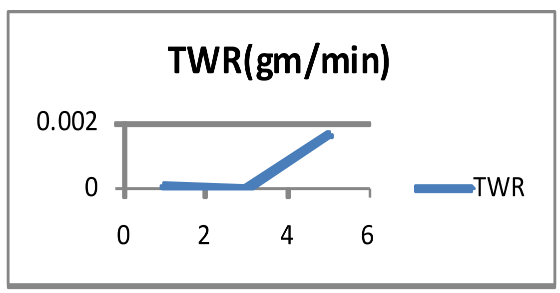


Fig 2(a) Effect on TWR with current (Ip) when pulse on is 50 µs

It is observed that with an increase in discharge current, TWR increases shown in fig 2(b) and (c) because as the current increases higher energy is available for the electrode wear. This causes more and more erosion of tool material with increase in current. But when the pulse is 500 μs the erosion is less as compare to other cases.

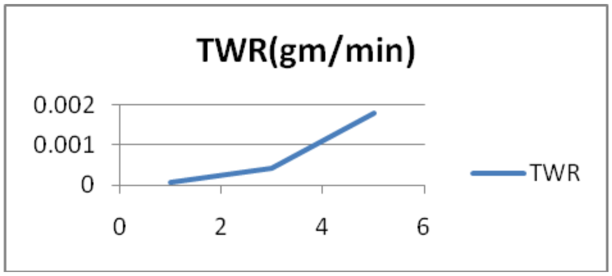


Fig.2(b) influence of TWR with current(Ip) when the pulse on is 500μs

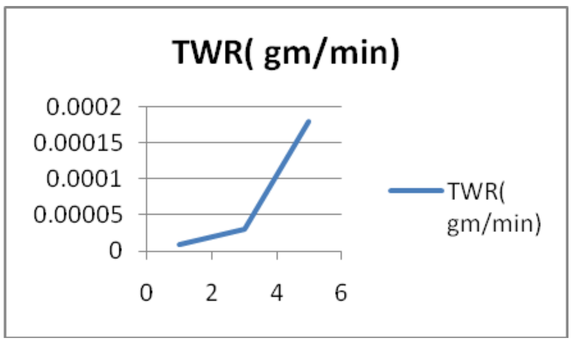
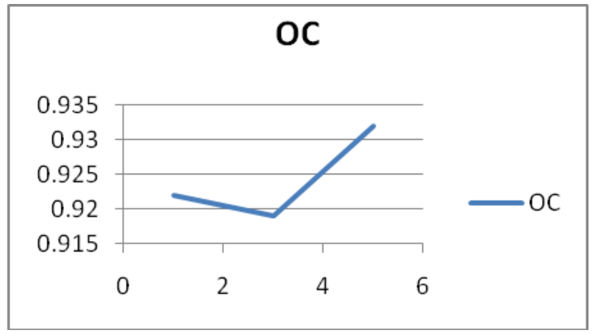


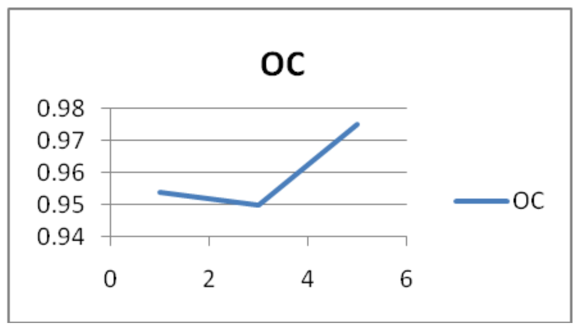
Fig.2(c) influence of TWR with current(Ip) when the pulse on is 1000μs

VII. Analysis of OC (Overcut)

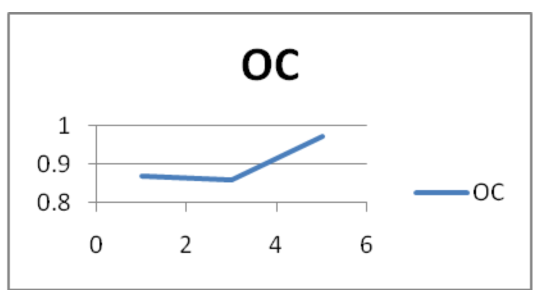
The over cut between the dimension of the electrode and the size of the cavity it is inherent to the EDM process which is unavoidable though adequate compensation are provided at the tool design. To achieve the accuracy, minimization of over cut is essential. Therefore factors affecting of over cut is essential to recognize. The over cut are effect to each parameter such as diameter of tool, discharge current and pulse on time. This graphs are represent the diameter of tool is directly proportional to the over cut. Increasing in the discharge current from 1 to 3 A the OC is decreasing, with increase in discharge current from 3A to 5A the OC increasing slightly. Whereas, OC increases monotonically with the increase in pulse on time. Because which is responsible for production of spark of tool and workpiece interface. it is given previous researchers **Jeswani**. And The interaction plot of OC is shown in Fig 4.8, where each plot exhibits the interaction between three different machining parameters like Ip Ton and dia. of tool. This implies that the effect of one factor is dependent upon another factor.



Graph 3(a). Overcut with discharge current for pulse on 50 μs



Graph 3(b). Overcut with discharge current for pulse on 500μs



Graph 3(c) Overcut with discharge current for pulse on 1000 μs.

VIII. Conclusion:

1. According to our objective, yes it is feasible of machining EN-19 tool steel using U-shaped tubular copper electrode and internal flushing by electric discharge machine.
2. By the Use of the taguchi design approach (Minitab software) experiment design is done.
3. After then calculating the values of MRR, TWR and OC of all 18 experiments.
4. After then draw all the graphs which shows the influence of current on MRR, TWR and OC.

   As we know that maximum MRR is necessary for the work piece. When the current increases the MRR is also increases but when the pulse on is increasing the MRR is decreasing monotonically. so if we want to increase the MRR we have to reduce the Pulse on. When the pulse on is minimum (50 µs) the MRR is 4.634 mm3/min . MRR is nor depend on the dia of electrode.

5. As we know that Minimum TWR is very essential for the tool life. So from the graphs of TWR as the pulse on is increasing the TWR is increasing. At minimum pulse on minimum TWR. When pulse on is minimum (50µs) TWR is 0.0016gm/min.
6. Overcut is directly proportional to the dia of the electrode . It is also depend on current and pulse on. As the current increases the overcut is also increasing. As the pulse is increases the overcut is also increases. But for the accuracy the requirement I minimum overcut . so minimum pulse on is better. At 50 µs the overcut is minimum 0.932mm.

References

[1]. Dhar, s., Purohit, r., Saini, n., Sharma, a. and Kumar, G.H., 2007. Mathematical modeling of electric discharge machining of cast Al-4Cu-6Si alloy-10 wt.% sicp composites. *Journal of Materials Processing Technology, 193(1-3), 24-29.*

[2]. Karthikeyan R, Lakshmi Narayanan, P.R. and Naagarazan, R.S., 1999. Mathematical modeling for electric discharge machining of aluminium-silicon carbide particulate composites. *Journal of Materials Processing Technology, 87(1-3), 59-63*

[3]. Mohan, B., Rajadurai, A. and Satyanarayana, K.G., 2002. Effect of sic and rotation of electrode on electric discharge machining of Al-sic composite. *Journal of Materials Processing Technology, 124(3), 297-304.*

[4] Vijay kumar , Naveen Beri, Anil and Paramjit singh, jully- sept. 2010some study of electric discharge machining of hastelloy using powder metallurgy electrode, *International journal of advanced engineering technology, E-ISSN 0976-3945.*

[5]H.K Kansal, sahijpal singh & Pardeep kumar, 13 june 2006,*International journal of engineering & material sciences, performance parameters optimization(multi-characteristics) of powder mixed electric discharge machining through taguchi's method and utility concept, vol. 13.*

[6]. Yan, B.H., Wang, C.C., Chow, H.M. and Lin, Y.C., 2000. Feasibility study of rotary electrical discharge machining with ball burnishing for Al2O3/6061Al composite. *International Journal of Machine Tools and Manufacture, 40(10), 1403-1421.*

[7]. Yan-Cherng Lin, Yuan-feng chen, Ching-tien Lin, AND Hsinn-jyh Tzeng Feasibility study of rotary electrical discharge machining with ball burnishing for Al2O3/6061Al composite 2008, vol.23: 391–399,.

[8]. Puertas, I. And Luis, C.J., 2004. A study of optimization of machining parameters for electrical discharge machining of boron carbide. *Materials and Manufacturing Processes, 19(6), 1041-1070.*

[9]. Tsai, H.C., Yan, B.H. and Huang, F.Y., 2003. EDM performance of Cr/Cu-based composite electrodes. *International Journal of Machine Tools and Manufacture, 43(3), 245-252.*

[10]. Saha, S.K. and Choudhury, S.K., 2009. Experimental investigation and empirical modeling of the dry electric discharge machining process. *International Journal of Machine Tools and Manufacture, 49(3-4), 297-308.*

[11]. Lin and Tung-Han United States Patent 6,768,077 Lin July 27, 2004.

[12]. Sohani, M.S., Gaitonde, V.N., Siddeswarappa, B. And Deshpande, A.S., 2009. Investigations into the effect of tool shapes with size factor consideration in sink electrical discharge machining (EDM) process. *International Journal of Advanced Manufacturing Technology, , 1-15.*

[13]. Zhou, M. And Han, F., 2009. Adaptive control for EDM process with a self-tuning regulator. *International Journal of Machine Tools and Manufacture, 49(6), 462-469.*

[14]. Izquierdo, B., Sánchez, J.A., Plaza, S., Pombo, I. And Ortega, N., 2009. A numerical model of the EDM process considering the effect of multiple discharges. *International Journal of Machine Tools and Manufacture, 49(3-4), 220-229.*

[15] Wei; Bin, and Lee; Martin Kin-fei April 16, 2002. *Apparatus and method for electrical discharge machining multiple holes United States Patent 6,373,018, et al.*

[16]. Kung, K.-., Horng, J.-. and Chiang, K.-., 2009. Material removal rate and electrode wear ratio study on the powder mixed electrical discharge machining of cobalt-bonded tungsten carbide. *International Journal of Advanced Manufacturing Technology, 40(1-2), 95-104.*

[17]. Ding, S. and Jiang, R., 2004. Tool path generation for 4-axis contour EDM rough machining. *International Journal of Machine Tools and Manufacture, 44(14), 1493-1502.*

[18]. Bleys, P., Kruth, J.-., Lauwers, B., Zryd, A., Delpretti, R. And Tricarico, C., 2002. Real-time tool wear compensation in milling EDM. CIRP Annals - Manufacturing Technology, 51(1), 157-160.