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Experimentation on electric discharge machining parameters and their effects on material removal rate, tool wear rate and overcut

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ABSTRACT

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 capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mould making industries, aerospace, aeronautics and nuclear industries.

AISI P20 Plastic mould steel that is usually supplied in a hardened and tempered condition. Good machinability, better polishability, it has grooving rang of application in plastic moulds, frames for plastic pressure dies, hydro forming tools. These steel are categorized as difficult to machine materials, posses greater strength and toughness are usually known to create major challenges during conventional and non-conventional machining. The Electric discharge machining process is finding out the effect of machining parameter such as discharge current, pulse on time and diameter of tool material. Using U-shaped copper tool with internal flushing. A well-designed experimental scheme was used to reduce the total number of experiments. The experiments were conducted with the L18 orthogonal array based on the Taguchi method. Moreover, the signal-to-noise ratios associated with the observed values in the experiments were determined by which factor is most affected by the Responses of Material Removal Rate (MRR), Tool Wear Rate (TWR) and over cut (OC).

Keywords - *Material removal rate (MRR), Tool wear rate, Over cut (OC), Pulse on time, Pulse off time, polishability*

1. Introduction

Electro Discharge Machining (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.

In EDM process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. Show the mechanical set up and electrical set up and electrical circuit for electro discharge machining. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system shown in Fig.1. Both tool and work piece are submerged in a dielectric fluid (kerosene/EDM oil/deionized water).

This Fig.1 shows the electric setup of the Electric discharge machining. The tool is made cathode and work piece is anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of from 10 of micro seconds. The positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between

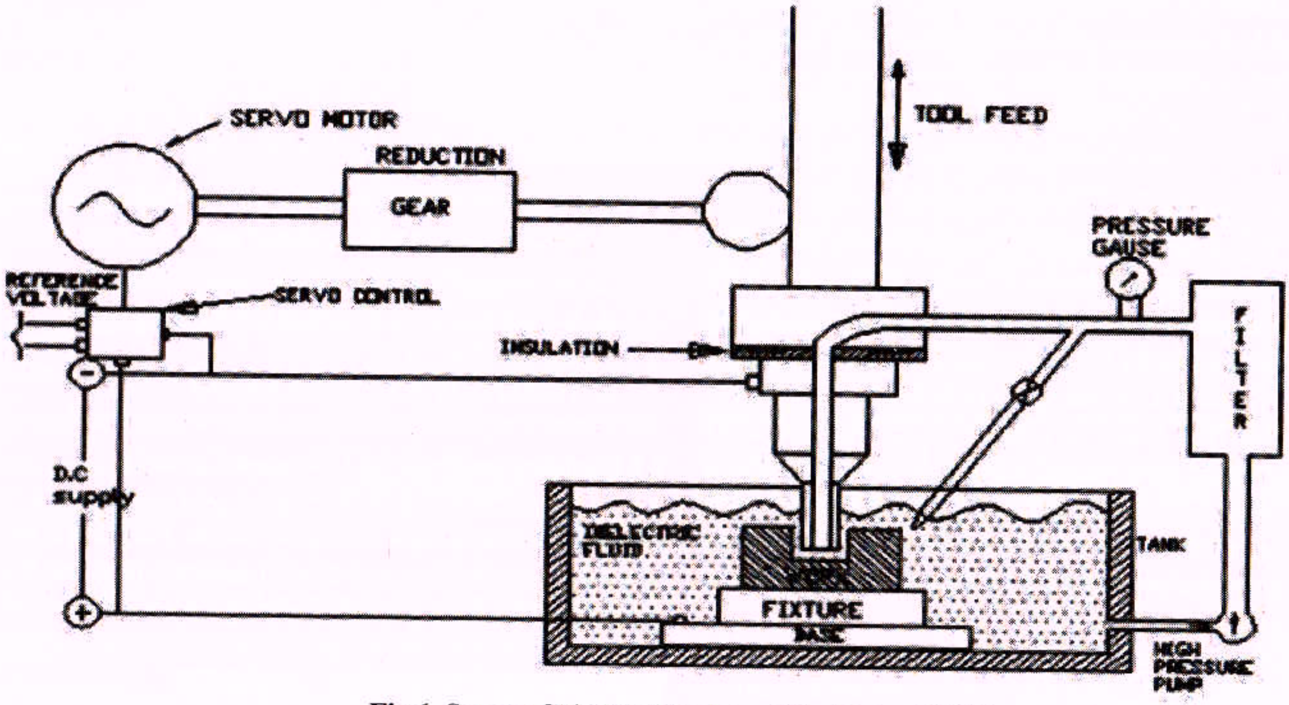

Fig.1. Set up of Electric Discharge Machining (EDM)

ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached and at such high pressure and temperature that some metal is melted and eroded.

As the potential difference is withdrawn as shown in Fig. 2, 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.

Dhar and Purohit [1] evaluates the effect of current (c), pulse-on time (p) and air gap voltage (v) on MRR, TWR, ROC of EDM with **Al–4Cu–6Si alloy–10 wt. % SiC_p composites**. This experiment has done on the PS LEADER ZNC EDM machine and a cylindrical brass electrode of 30 mm diameter.

Singh et al. [2] discuss the evolution of effect of the EDM current (*C*), Pulse ON-time (*P*) and flushing pressure (*F*) on MRR, TWR, taper (*T*), ROC, and surface roughness (SR) on machining as-cast Al-MMC with 10% SiCp and use of metal matrix composites. ELEKTRAPULS spark erosion machine was used for the purpose and jet flushing of the dielectric fluid, kerosene, was employed. Brass tool of diameter 2.7 mm was chosen to drill the specimens. An L27 OA, for the three machining parameters at three levels each, was opted to conduct the experiments. ANOVA was performed and the optimal levels for maximizing the responses were established.

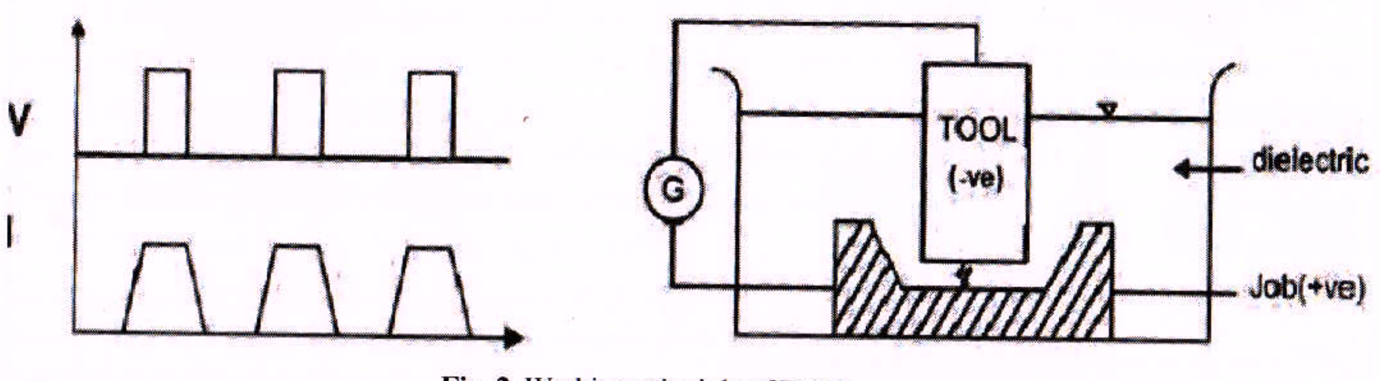

Fig. 2. Working principle of EDM process

The investigation was carried out on die sinking EDM for U shaped Cu tool material and AISI P20 plastic mould steel work piece material. The results were obtained for MRR, TWR and OC and briefly narrated in this paper.

2. Experimental setup:

The experiment work is done 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= 94ÚC) was used as dielectric fluid. With internal flushing of U-shaped cu tool with a pressure of 0.2 kgf/cm^2. Experiments were conducted with positive polarity of electrode. The pulsed discharge current was applied in various steps in positive mode.

In the Sinker EDM process, two metal parts submerged in an insulating liquid are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts. If the two parts are brought together to within a fraction of an inch, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts. Sinker EDM, also called cavity type EDM or volume EDM consists of an electrode and work piece submerged in an insulating liquid such as, more typically, oil or, less frequently, other dielectric fluids. Table 1 gives the specifications of die sinking EDM machine considered for the material removal of work piece made of AISI P 20 (plastic mould steel).

The EDM consists of following major part as shown in the chapter Appendix

1. Dielectric reservoir, pump and circulation system
2. Power generator and control unit
3. Working tank with work holding device
4. X-y table accommodating the working table
5. The tool holder
6. The servo system to feed the tool

2.1 Flushing method for U shaped Cu tool:

Flushing is the most important function in any electrical discharge machining operation. Flushing is the process of introducing clean filtered dielectric fluid into the spark gap. There are a number of flushing methods usec

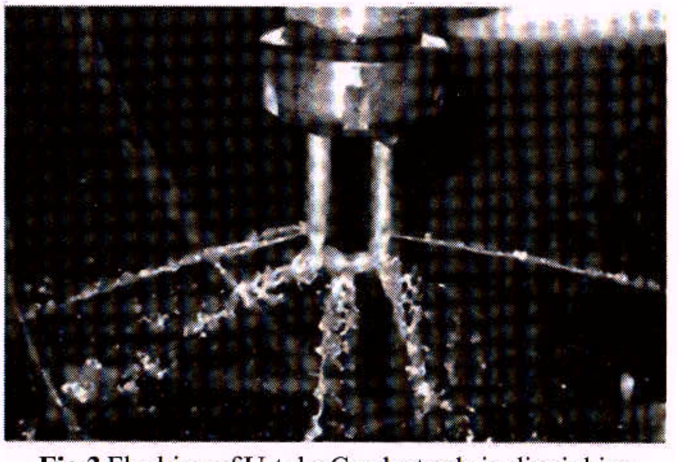

Fig.3 Flushing of U-tube Cu electrode in die sinking EDM

Table. 1. Specification of die-sinking type EDM

Mechanism of process	Controlled erosion (melting and evaporation) through a series of electric spark
Spark gap	0.010- 0.500 mm
Spark frequency	200 – 500 kHz
Peak voltage across the gap	30- 250 V
Metal removal rate (max.)	5000 mm^3/min
Specific power consumption	2-10 W/mm^3/min
Dielectric fluid	EDM oil, Kerosene liquid paraffin, silicon oil, deionized water etc.
Tool material	Copper, Brass, graphite, Ag-W alloys, Cu-W alloys
MRR/TWR	0.1-10
Materials that can be machined	All conducting metals and alloys
Shapes	Microholes, narrow slots, blind cavities
Limitations	High specific energy consumption, non conducting materials can't be machined

to remove the metal particles efficiently. This experiment is using the internal flushing with the Cu U- shaped tool shown in the Fig. 3.

2.2 Tool material:

Tool material should be such that it would not undergo much tool wear when it is impinged by positive ions. Thus the localized temperature rise has to be less by tailoring or properly choosing its properties or even when temperature increases, there would be less melting. Further, the tool should be easily workable as intricate shaped geometric features are machined in EDM. Thus the basic characteristics of electrode materials are:

1. High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating.
2. High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear.
3. Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy.
4. High melting point – high melting point leads to less tool wear due to less tool material melting for the same heat load.
5. Easy manufacturability.
6. Cost – cheap.

2.3 Work piece material:

It is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. There are different types of tool material are using the EDM method. And the tool steel contains carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures (red-hardness). Tool steel is generally used in a heat-treated state. Tool steels are made to a number of grades for different applications. In general, the edge temperature under expected use is an important determinant of both composition and required heat treatment. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools, etc. In this experiment AISI P-20 plastic mould tool steel is used as work material. The flow chart of experimentation work carried out on die electric EDM on AISI P 20 plastic mould steel work piece has been shown in Fig.4.

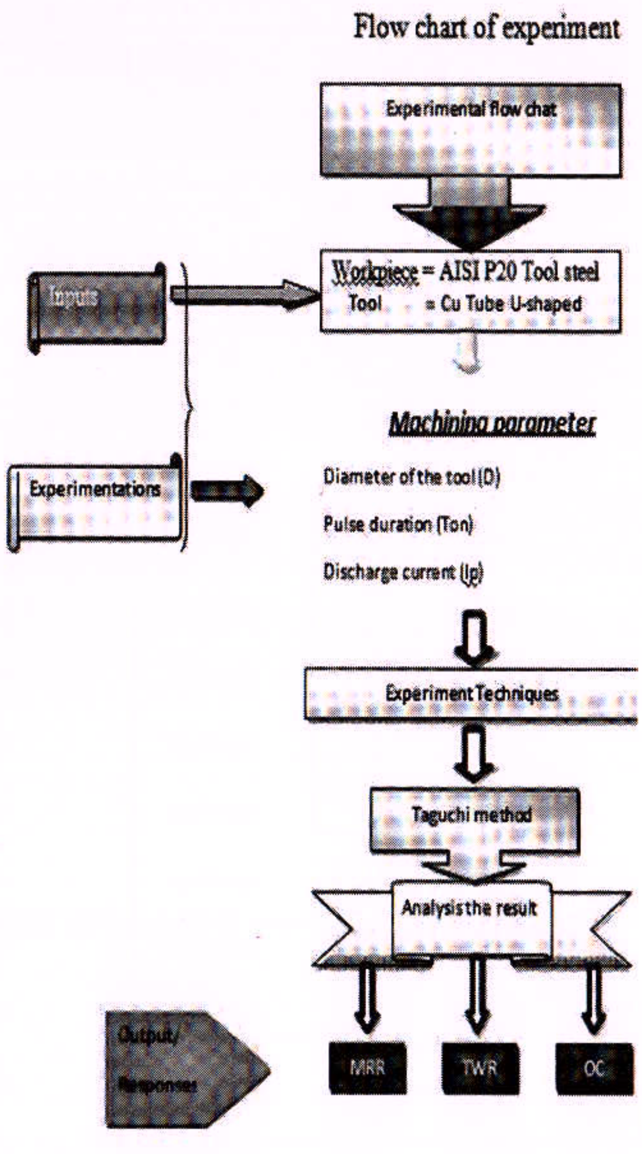

Fig. 4 Flow chart of experimental work on die sinking EDM

AISI P20 tool steel material and after machining work piece and the Cu U-shaped tool. As shown in Fig 5 and there are total 18 readings taken from the experiment. 2.4 Mechanism of metal removal from die electric EDM

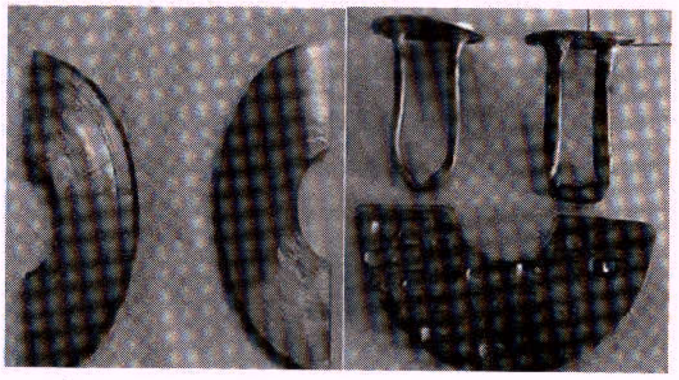

Fig.5. AISI P-20 work piece before and after machining with Cu U-shaped tool

The mechanism of material removal of EDM process is most widely established principle is the conversion of electrical energy it into thermal energy. During the process of machining the sparks are produced between work piece and tool .Thus each spark produces a tiny crater, and crater formation shown in this Fig 6 in the material along the cutting path by melting and vaporization, thus eroding the work piece to the shape of the tool.

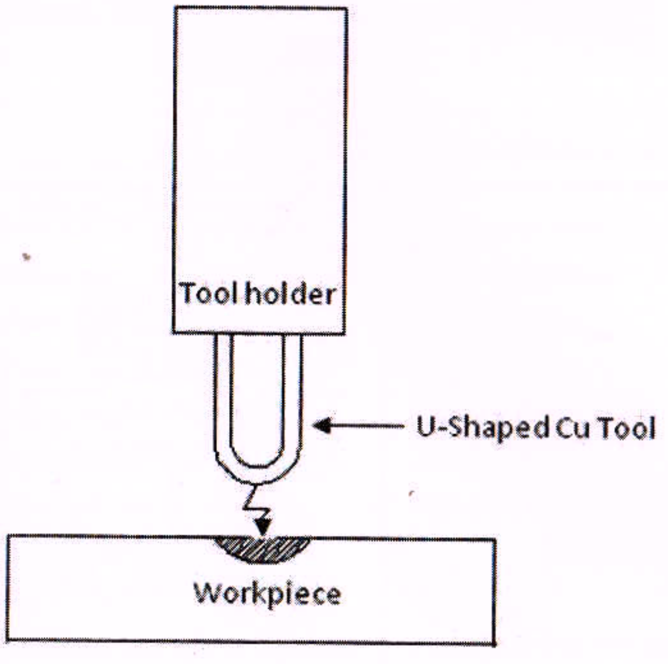

Fig.6 Mechanicsm of metal removal in die sinking type EDM

3. Evaluation of parameters:

The material removal rate (MRR) is expressed as the ratio of the difference of weight of the work piece before and after machining to the machining time and density of the material as follows:

$$MRR = \frac{W_{jb} - W_{ja}}{t \times \rho}$$

Where, MRR (cm^3/h), W_{jb} and W_{ja} are weight of work piece before and after machining, (g), t –machining time, (h) and Rho– density of work piece material (g/cm^3)

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.

$$TWR = \frac{W_{tb} - W_{ta}}{t}$$

Where, TWR (g/h), W_{tb} and W_{ta} are weight of tool material before and after machining, (g), t –machining time, (h)

Over cut (OC) is expressed as half the difference of diameter of the hole produced to the tool diameter.

$$OC = \frac{D_{jt} - D_t}{2}$$

Where, D_{tt} and D_t are diameter of hole produced in the work piece and diameter of the tool, (mm).

4. Results and discussion:

The influences of MRR, TWR, and OC and finding the resulting factors such as discharge current, pulse duration, diameter of Cu tool is determined using Taguchi method. The response table for MRR, TWR and OC is given in Table 2.

The analysis of variances for the factors is shown in Table 3 which clearly indicates that the diameter of the tool is less important for influencing MRR and Ip and Ton are the most influencing factors for MRR and as well as the interaction Ip x Ton is significant (shown by bold font in Table 3). and other factors are less significant. The delta values are diameter of tool, Ton and Ip are 1.1493, 15.0841 and 18.3901 respectively, depicted in Table 3. The Metal Removal Rate, should be large. It is clear that Ip is the most important factor, secondly Ton and last is diameter of the tool.

During the process of Electrical discharge machining, the influence of various machining parameter like Ip, Ton and Diameter of tool has significant effect on MRR, as shown in main effect plot for S/N ratio of MRR in Fig 7. The discharge current (Ip) is directly proportional to MRR in the range of 1 to 3A. This is expected because an increase in pulse current produces strong spark, which produces the higher temperature, causing more material to melt and erode from the work piece. Besides, it is clearly evident that the other factor does not influence much as compared to Ip and similar conclusions were shown by

Table 2. Response table for MRR, TWR and OC using Taguchi method

Run	Dia(mm)	Ip(A)	Ton(µs)	MRR(mm^3/min)	TWR(gm/min)	OC(mm)
1	4	1	50	1.0400	0.0170	0.8620
2	4	1	500	0.2360	0.0030	0.6965
3	4	1	1000	0.0360	0.0006	0.3680
4	4	3	50	3.9890	0.0660	0.9410
5	4	3	500	0.9040	0.0150	0.8715
6	4	3	1000	0.7970	0.0130	0.7225
7	4	5	50	2.9980	0.0400	0.9295
8	4	5	500	1.7770	0.0290	0.8790
9	4	5	1000	0.8000	0.0030	0.9820
10	6	1	50	0.6140	0.0103	0.1435
11	6	1	500	0.2950	0.0040	0.0895
12	6	1	1000	0.0700	0.0010	0.0710
13	6	3	50	3.0000	0.0500	0.5790
14	6	3	500	1.1120	0.0180	0.5650
15	6	3	1000	0.9738	0.0356	0.5720
16	6	5	50	2.9700	0.0490	0.5900
17	6	5	500	2.2390	0.0370	0.5680
18	6	5	1000	1.3000	0.0105	0.5120

Table. 3. Analysis of variance for S/N ratios for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Dia	1	5.94	5.94	5.944	3.38	0.140
Ip	2	1222.40	1222.40	611.198	347.29	**0.000**
Ton	2	683.05	683.05	341.524	194.06	**0.000**
Dia*Ip	2	2.17	2.17	1.087	0.62	0.584
Dia*Ton	2	30.98	30.98	15.491	8.80	0.034
Ip*Ton	4	163.28	163.28	40.820	23.19	**0.005**
Residual Error	4	7.04	7.04	1.760		
Total	17	2114.86				

Ghoreishi and Tabari [3]. But, with increase in discharge current from 3A to 5A MRR increases slightly. However, MRR decreases monotonically with the increase in pulse on time.

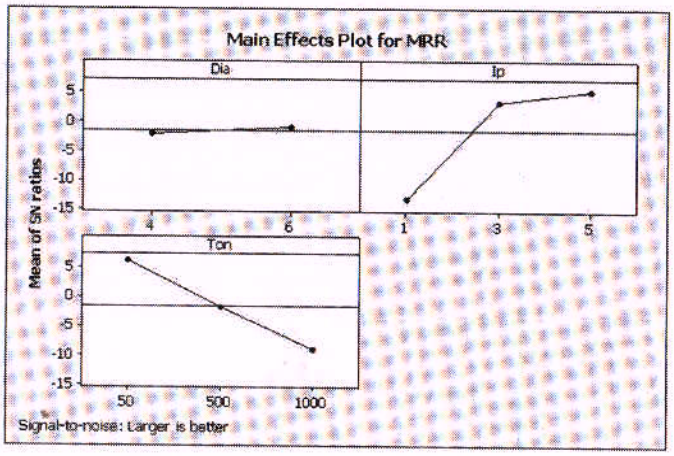

Fig.7. Main effect plots for MRR

During the process of EDM, the influence of various machining parameter like Ip, Ton and Diameter of tool has significant effect on TWR , as shown in main effect plot for S/N ratio of TWR in Fig 8. 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 [1].

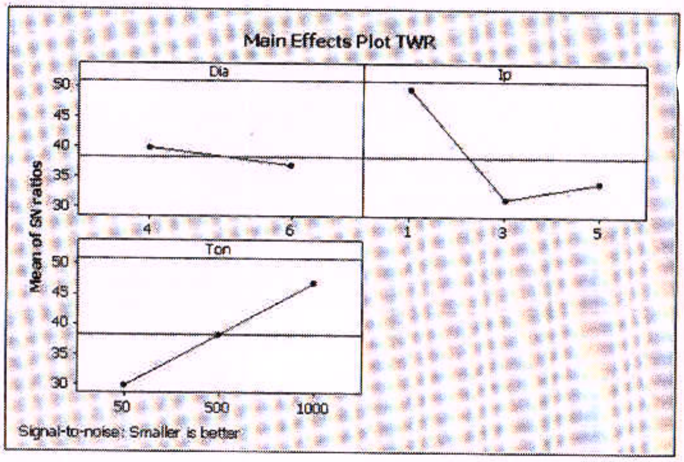

Fig.8. Main effect plots for TWR

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, the main effect

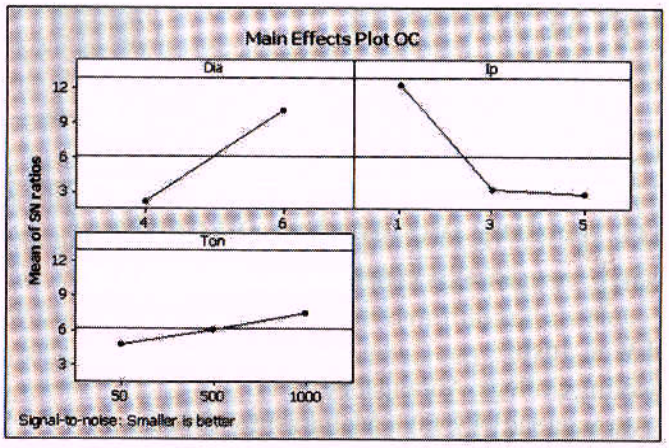

Fig. 9 Main effect plots for OC

plot for S/N ratios shown by Fig 9 for over cut. These Figs. 7-9 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 [4].

5. Conclusion:

In the present study on the effect of machining responses are MRR, TWR and OC of the AISI P20 plastic mould steel component using U-Shaped copper 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 analyse the result and theses responses were partially validated experimentally.

1. Find the result of MRR discharge current is most influencing factor followed by pulse duration time and diameter of the tool. MRR increased with the discharge current (Ip).As the pulse duration extended, the MRR decreases monotonically.

2. In the case of tool wear rate the most significant factor is discharge current followed by pulse on time and diameter of tool

3. In the case of overcut, the most significant factor is discharge current followed by diameter of the tool and pulse on time

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