PARAMETRIC OPTIMIZATION OF MATERIAL REMOVAL RATE DURING ELECTRICAL DISCHARGE MACHINING OF AISI H-13 TOOL STEEL USING COPPER ELECTRODE WITH INTERNAL FLUSHING BY TAGUCHI METHOD

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ABSTRACT

Electric discharge machining(EDM) is one of the most popular machining methods to manufacture dies and press tools because of its capability to produce complicated shapes and machine very hard materials. 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. In this research paper an attempt has been made to study the effect of different machining parameters viz. discharge current, pulse on time and thickness of tool on machining of AISI H 13 tool steel material using an U-shaped cu tool with internal flushing. It is found that these control factors have a significant influence on material removal rate. In order to see the impact of control factors on material removal rate, number of experiments was conducted and results were analyzed by Taguchi Methodology and analysis of variance. Main effect plot and interaction plot for significant factors and S/N ratio have been used to determine the optimal design for output response. The effect of control factors were examined for obtaining best parameter setting. The analysis of Taguchi method reveals that, discharge current, pulse on time and thickness of tool has significant effect on the material removal rate.

KEYWORDS: Electric discharge machining, Taguchi method, material removal rate

1.INTRODUCTION

Considering the challenges brought on by advanced technology, the Electrical Discharge Machining (EDM) process is one of the best alternatives for machining an ever increasing number of high-strength, non-corrosion, and wear resistant materials . AISI H13 tool steel is considered as a significant material that has a widespread application in mould industries. Electrical discharge machining is a non-traditional machining method commonly used to produce die cavities with the erosive effect of electrical discharges. It uses thermo electric energy sources for machining low machinability materials; a complicated intrinsic-extrinsic shaped job regardless of hardness has been its distinguishing characteristics. EDM founds its wide applicability in manufacturing of plastic moulds, forging dies, press tools, die castings, automotive, aerospace and surgical components.EDM has its wide applications in manufacturing of plastic moulds, forging dies, press tools, die castings, automotive, aerospace and surgical components. No direct contact is made by EDM between the electrode and the work piece. It

annihilates mechanical stresses, chatter and vibration problems during machining. Various types of EDM process are available, but here it is Die-Sinking type EDM machine which requires the electrode to be machined in the exact contradictory shape as the one in the work piece. Electrical discharge machining utilizes rapid, repetitive spark discharges from a pulsating direct-current power supply between the work piece and the tool submerged into a dielectric liquid. The thermal energy of the sparks leads to intense heat conditions on the work piece causing melting and vaporizing of the work piece material.

EDM PROCESS

EDM, as shown in figure 1.1, basically a thermo electric process, has the ability to machine any conducting materials regardless of their mechanical and chemical properties. As there is no contact between the tool and the work piece required, it is very efficient and effective in machining very hard and high strength materials.

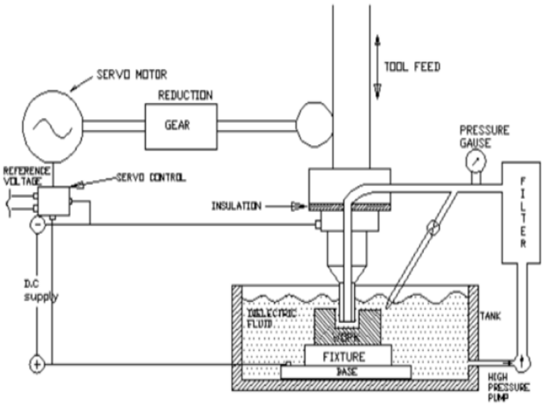

Figure1. 1 Set up of Electric discharge machining

In EDM, a power supply hands over high-frequency electric pulses to the electrode tool and the work piece. The gap between the tool and work piece is flushed with a flow of dielectric liquid. When an electric pulse is delivered from the electric supply, the insulating property of the die electric fluid is temporarily made ineffective. This permits a small spark to fly the shortest distance between the tool and work piece. A small pool of molten metal is shaped on the work piece and the tool at the point of discharge. A gas boils form around the discharge and the molten pools. As the electric pulse ends and the discharge disappears, the gas boil collapses. The wave of cool dielectric causes the molten metal to be ejected from the work piece and the tool, leaving small craters. This action is repeated no. of times each second during EDM processing. This removes material from the work piece in a shape corresponding to that of the tool. Electrical discharge machining (EDM) processes are now gaining in popularity, since many complex 3D shapes can be machined using a simple shaped tool electrode. Depending on the kind of material used and other requirements, positive or negative polarity can be applied. When gap width between the tool and the electrode achieves the maximum sparking gap width, a micro-conductive ionized path appears and the electric spark occurs achieving temperatures up to 15,000 or 20,000°C [2].

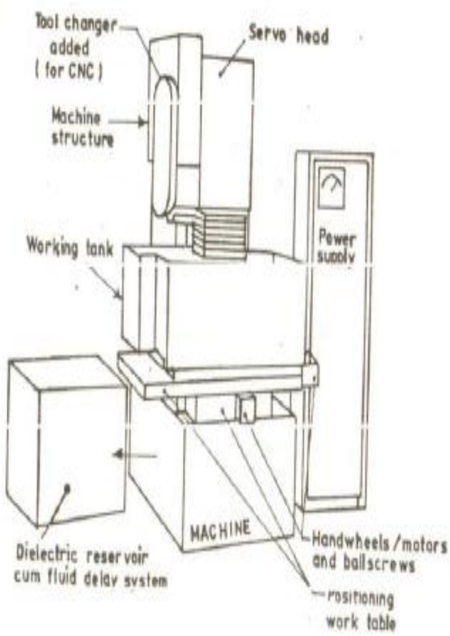

Figure 1.2 Parts of EDM

This paper aims to fill the gap in the existing literature with respect to the processing of AISI H13 tool steel with EDM. In particular, EDM machining experiments were conducted on AISI H13 samples using copper electrode to investigate the correlations between the EDM parameters (pulse on-time and current) and the EDM characteristics of such a work piece. The output factors investigated were the material removal rate. This experimental study results in the selection of optimum process parameters.

Table 2.1 Mechanical and physical properties of AISI H 13

Temperature in °C	Density in (kg/dm^3)	Specific heat in (J/Kg-K)	Electrical resistivity in (Ω mm2/m)	Modulus of elasticity in (N/mm^2)	Thermal conductivity in (W/m.K)
20	7.80	460	0.52	$215x10^3$	24.30
500	7.64	550	0.86	$176x10^3$	27.70
600	7.6	590	0.96	$165x10^3$	27.50
Liquidus temperature 1454°C			Solidus temperature 1315^{0}C		

2. EXPERIMENTAL SETUP AND PROCEDURE

The work piece material used in this study was AISI H13 tool steel. Prior to EDM processing, the work piece was cut in a rectangular shape(5 mm and 6 mm thickness) and after it was filed to an U-shape with drilled inside for the purpose of internal flushing. The main mechanical and physical properties of such work piece material at different temperatures are given in Table 2.1.

The tool material was forged commercial pure copper with the main properties given in Table 2.2. The experiments were performed on a die sinking EDM machine ELECTRONICA M2S EMS 5030 (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/cm2 .Experiments were conducted with positive polarity of electrode. The pulsed discharge current was applied in various steps in positive mode. Machining tests were carried out for two electrode thickness at three pulse current settings, as well as three pulse on time settings.

Table 2.2 Physical properties of copper electrode

Physical properties	Copper
Thermal conductivity(W/m.K)	380.7
Melting point in °C	1083
Boiling temperature in ° C	2595
Specific heat(Cal/g-°C)	0.092
Specific gravity at 20 ° (g/cm^3)	8.9
Coefficient of thermal expansion[$x10^{-6}$(1/°c)]	17

As a result, 18 experiments could be designed as per Taguchi method. Each machining test was performed for 60 minutes. Table 2.3 presents the experimental test conditions.

Eqs. (1) shows the calculations used for assessing the values of *MRR*.

$MRR = (M1 - M2) / (\rho_w \cdot T)$ .... (1)

where $M1$ and $M2$ are the weight of work piece before and after machining [g], respectively. ρ_w is the density of work piece [g/mm3], and T is the machining time [min].

Table 2.3 Experimental test conditions

Generator type	ELECTRONICA M2S EMS 5030
Dielectric fluid	Commercial grade EDM oil
Voltage	415 V,3 phase,5 HZ
Open gap voltage	135 V
Pulse range	2 to 650 µs
Pulse on time	100,200,400 µs
Max. Current	25A
Pulse current	1A,3A,5A
Load	3 KVA
Power factor	0.8 approx.

2.1 WORK PIECE MATERIAL

AISI H 13 tool steel material work piece before and after machining and the Cu U-shaped tool is shown in Fig 2.1.It shows 18 no. of experiments(9 no. of experiments per side) were performed in this job

Fig.2.1 H-13 Work piece before and after machining with tool

2.2 TOOL MATERIAL

In this experiment ,copper tool electrode was used and the design of cupper tool is a U- shaped with internal flashing. Shapes of the tool are same as that of the cavity produced in the work piece. Using the U-shaped tool an U-shaped cavity is produced on the work piece. The design of the tool is showed in Fig 2.2 .

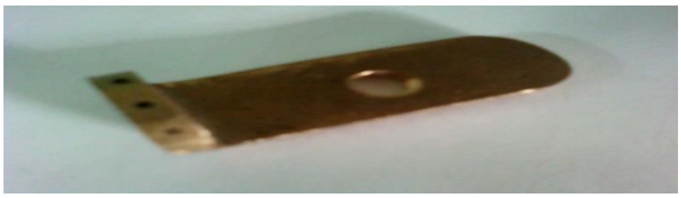

Fig.2.2 U-Shaped cu Tool Design

2.3 MECHANISM OF MRR

The mechanism of material removal of EDM process is most widely established principle. It is the conversion of electrical energy 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 , the material along the cutting path by melting and vaporization, thus eroding the work piece to the shape of the tool.

It is well-known and elucidated by many EDM researchers that Material Removal Mechanism (MRM) is the process of transformation of material elements between the work-piece and electrode. The transformation are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a solid, liquid or gaseous phase reaction.

2.4 TAGUCHI DESIGN EXPERIMENTS

The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors.

A Taguchi design or an orthogonal array is the method of designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, a three factor mixed level setup is chosen with a total of eighteen numbers of experiments to be conducted and hence the OA L18 was chosen. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L18 setup, which in turn would reduce the number of experiments at the later stage. In addition, the comparison of the results would be simpler.

The levels of experiment parameters electrode thickness(t), spark on time (Ton), and discharge current (Ip) are shown in Table 3.5 and the design matrix is depicted in Table 2.4.

Table 2.4 Machining parameters and their levels

Machining Parameter	Symbol	Unit	Level		
			Level 1	Level 2	Level 3
Electrode Thickness	t	mm	5.2	6.2	-
Spark on time	T_{on}	µs	200	300	400
Discharge Current	I_p	A	1	3	5

Table 2.4 Design matrix and Observation table

Run	Thick ness (mm)	Ip (A)	Ton (µs)	Wt of Workpiece in (kg)		Wt. of Tool in (kg)	
				Wjb	Wja	Wtb	Wta
1	5.2	1	200	1.261	1.259	0.252	0.252
2	5.2	1	300	1.259	1.258	0.252	0.252
3	5.2	1	400	1.258	1.257	0.252	0.252
4	5.2	3	200	1.257	1.253	0.252	0.251
5	5.2	3	300	1.253	1.251	0.251	0.250
6	5.2	3	400	1.251	1.250	0.250	0.250
7	5.2	5	200	1.250	1.245	0.250	0.248
8	5.2	5	300	1.245	1.242	0.248	0.247
9	5.2	5	400	1.242	1.241	0.247	0.246
10	6.2	1	200	1.314	1.310	0.264	0.264
11	6.2	1	300	1.310	1.308	0.264	0.264
12	6.2	1	400	1.308	1.307	0.264	0.264
13	6.2	3	200	1.307	1.297	0.264	0.263
14	6.2	3	300	1.297	1.291	0.263	0.263
15	6.2	3	400	1.291	1.288	0.263	0.263
16	6.2	5	200	1.288	1.274	0.263	0.262
17	6.2	5	300	1.274	1.266	0.262	0.261
18	6.2	5	400	1.266	1.261	0.261	0.261

3. RESULT AND CONCLUSION

The response table for MRR is shown in Table 3.1

Table 3.1 Response table

Run	Thickness (mm)	Ip (A)	Ton (µs)	MRR (mm^3/min)
1	5.2	1	200	4.296
2	5.2	1	300	2.148
3	5.2	1	400	2.148
4	5.2	3	200	8.592
5	5.2	3	300	4.296
6	5.2	3	400	2.148
7	5.2	5	200	10.740
8	5.2	5	300	6.444
9	5.2	5	400	2.148
10	6.2	1	200	8.592
11	6.2	1	300	4.296
12	6.2	1	400	2.148
13	6.2	3	200	21.480
14	6.2	3	300	12.890
15	6.2	3	400	6.444
16	6.2	5	200	30.072

17	6.2	5	300	17.184
18	6.2	5	400	10.740

3.1 INFLUENCES ON MRR

The S/N ratios for MRR are calculated as given in Equation 4.1. Taguchi method is used to analyse the result of response of machining parameter for **larger is better** criteria.

S/N = -10 Log 10 (M.S.D)...............3.1

Where M.S.D. = Mean squared deviation = $1/Yi^2$ and Y_i = The value of response variables for i^{th} experiment.

The analysis of variances for the factors is shown in Table 4.2. From table 4.4 it is clearly evident that spark on time is the most important factor then electrode thickness and last is discharge current.

Table 3.2 Mean (S/N) ratios response Table for MRR

Symbol	Process parameter	Level 1	Level 2	Level 3
A	Electrode Thickness	A1=11.93	**A2=19.767**	-
B	Discharge Current	B1=10.654	B2=17.169	**B3=19.722**
C	Spark on Time	**C1=21.142**	C2=15.842	C3=10.561

Table 3.3 Analysis of Variance of S/N ratios for MRR

Results of ANOVA for MRR						
Symbol	**Process parameter**	**Degrees of freedom**	**Sum of square**	**Mean square**	**F₀=(Mean square/ Mean square error)**	**Contribution %**
A	Electrode thickness	1	276.5	276.5	51.04	**29.43**
B	Discharge current	2	262.19	130.10	24.017	**27.9**
C	Spark on time	2	335.878	167.939	31.002	**35.75**
Error		12	65	5.417		6.92
Total		17	939.568			100

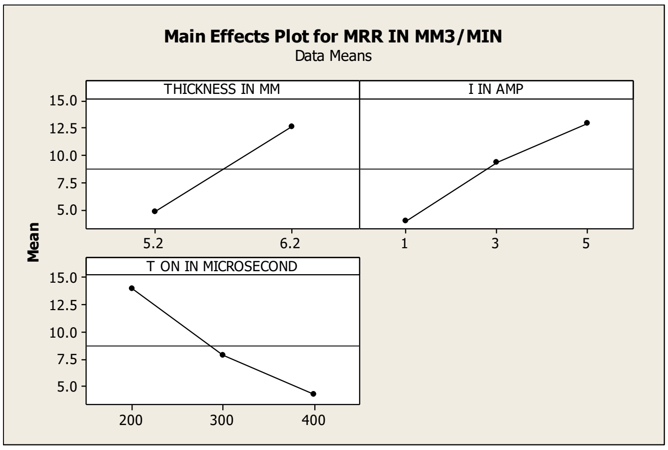

Figure 3.1 Main effect plot for MRR

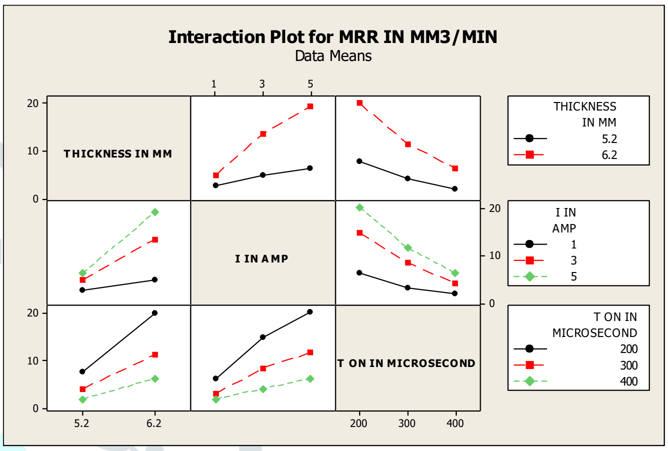

Figure 3.2 Interaction plot for MRR

3.2 SIGNIFICANT EFFECT

<u>Case (a)</u>

If $F_0 > F_{\alpha\ DOF,Error}$ then this process parameter significantly affects the experiment.

<u>Case (b)</u>

If $F_0 < F_{\alpha,DOF,Error}$ then this process parameter does not significantly affect the experiment.

The value of process parameters and their corresponding F_0 value can be obtained from table 4.4.

The value of $F_{\alpha,DOF,Error}$ can be obtained from percentage points of F distribution[6] .

Table 3.4 Factors which affects the experiment

Sl No.	Process parameter	DOF	F_0	$F_{\alpha,DOF,Error}$	Remarks
1	Electrode thickness	1	51.04	4.75	Significantly affects the experiment
2	Discharge current	2	24.017	3.89	Significantly affects the experiment
3	Spark on time	2	31.002	3.89	Significantly affects the experiment

3.3 MODEL ANALYSIS OF MRR

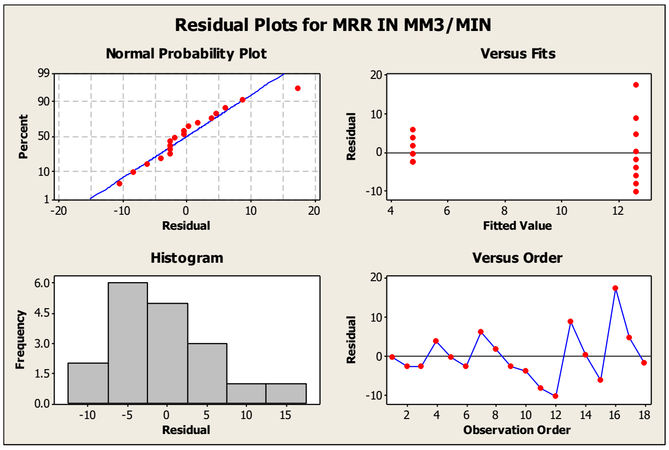

Fig.3.2 Residual plot for MRR

During the process of Electrical discharge machining, the influence of various machining parameters like Ip, Ton and thickness of tool have significant effect on MRR, as shown in main effect plot for S/N ratio of MRR in Fig 4.1. 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 higher temperature, causing more material to melt and erode from the work piece. But, with increase in discharge current from 3A to 5A MRR increases but not as rapidly as 1A to 3A. However, MRR decreases monotonically with the increase in pulse on time. It is well known fact that the spark energy increases with Ton .MRR usually increases with Ton up to a maximum value after which it starts to decrease. This is due to the fact that with higher Ton, the plasma formed between the Inter electrode gap (IEG) actually hinders the energy transfer and thus reduces MRR. So, the plotted graph of pulse duration vs. MRR, is showing decreasing trend only.

3.4 RESULT

S/N ratio has to be maximum for optimum.

$A_2B_3C_1$ ⟶ Optimum level of process parameter

Electrode thickness = 6.2 mm

Discharge current = 5A

Spark on time = 200 μs

Experiments were conducted according to Taguchi method by using the machining set up and the designed U-shaped tubular electrodes with internal flushing. In case of MRR pulse on time is most influencing factor and then electrode thickness and the last is discharge current.

3.5 CONCLUSION

In the present study of the AISI H 13 tool steel component machining using the U-Shaped cu tool with internal flushing system, the effect of machining parameters on MRR, of tool have been investigated for EDM process. The experiments were conducted under various parameters like Discharge Current (Ip), Pulse On-Time (Ton), and thickness of the tool. L-18 OA based on Taguchi design was used for analysis of the result and theses responses were partially validated experimentally.

(i)In case of MRR, pulse on time is most influencing factor and then electrode thickness and the last is discharge current.

(ii)All the three parameters have significant effect on the experiment.

REFERENCES

[1]. Lin, y., Cheng, C., Su, B. and Hwang, L., 2006. Machining characteristics and optimization of machining parameters of SKH 57 high-speed steel using electrical-discharge machining based on Taguchi method. Materials and Manufacturing Processes, 21(8), 922-929.

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

[3]. 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.

[4] Singh, Sanjeev Pratap,Verma, Amit Kumar,Meena, M L,17-18 December 2010,10th National Conference on Industrial Problems on Machines and Mechanisms (IPRoMM2010), MNIT, Jaipur, Rajasthan

[5] Text book of Taguchi Techniques for Quality Engineering by Phillip J. Ross in 1996, Mcgraw-hill international editions.

[6] Design and Analysis of Experiments by Douglas C. Montgomery in 2010,Wiley India(P) Ltd.

[7] A primer on the Taguchi method by R.K.Roy, Vanno strand Reinhold, New York 1990

[8] MINITAB 16 software