Machining Parameters Evaluations on Dimensional Accuracy in Abrasive Electric Discharge Machining (AEDM) Process Using Taguchi Methodology

Anil Kumar*, Naveen Beri, Harish Pungotra, Nripjit, Paramjit Singh

Abstract— These Dimensional accuracy is always important consideration in any machining process. The objective of this experimental study is to determine parameters that offer the best dimensional accuracy in abrasive mixed electrical discharge machining (AEDM). El trode polarity, electrode type, peak current, pulse on time, duty cycle, gap voltage, flushing pressure and abrasive concentration in dielectric are taken as machining parameters for blind hole operation on Hastelloy steel. The experimental investigations are carried out using copper and cryogenically treated copper electrode. L_{36} orthogonal array of Taguchi methodology is used to identify the effect of machining parameters on dimensional accuracy measured in terms of diametric overcut. Machining parameters are optimized for best dimensional accuracy. ANOVA analysis is carried out to identify the significant parameters that affect the hole accuracy. Confirmation tests are performed on at predicted optimum process parameters and results are verified. It is observed that abrasive concentration, peak current; polarity and electrode type are major significant parameters that effect dimensional accuracy in terms of overcut

Index Terms—AEDM, Taguchi method, overcut (OC), Abrasive particles concentration, peak current, polarity and electrode type, ANOVA

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1 INTRODUCTION

EDM, which removes material by the action of electrical discharges of short duration and high current density between tool and work piece, is highly useful for the machining of extra tough, hard, electrical conductive materials and alloys which are very difficult to machine by conventional machining methods It is widely using machining technique for applications such as manufacturing of molds, dies, automotive, nuclear reactor, spacecraft and surgical components. Although the electrical discharge maching (EDM) process is not affected by material hardness and strength, low machining efficiency and poor surface quality are the major drawbacks of this process that restricts its use in mechanical manufacturing as compared to milling and turning processes [1-3]. To enhance the material erosion rate of this process, large electrical current discharge is usually required, but concurrently the dimensional quality of the machined product inevitably became worse. Moreover, too much debris in spark gap at higher material removal rate leads to arching and hence instability of process. In the past decades, researchers did a lot of work to overcome these drawbacks and to develop an EDM process with the capability of high machining rate, and high precision and accuracy without major alterations to the EDM system. Rotating of electrode, orbiting of electrode, application of ultrasonic vibrations and addition of abrasive additives in dielectric fluid of EDM are some of the techniques suggested by researchers for this purpose. The use of ultrasonic vibrations to assist EDM process for improving the material removal rate was tried by . However, addition of conductive and semi conductive abrasive particles in dielectric fluid of EDM is more promising and reliable technique and is tried by many researchers [4-6]. In this technique, conductive abrasive particle are mixed properly in the dielectric fluid as represented in Figure 1.

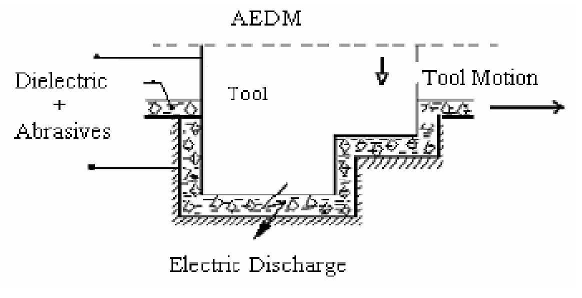

Fig.: 1 Principle of AEDM

When a suitable voltage (80-120V) is applied to the tool electrode and work piece, an electric potential in the range of 10^5 – 10^7 V/m is developed there with in the spark gap of 25-50 µm. The abrasive particles fill up the spark gap. Under the influence of high electric potential, these abrasive particles energized, get accelerated, act as conductors and form chains in sparking gap. Due to bridging of spark gap, the insulating strength of dielectric fluid reduces. This leads to increase in

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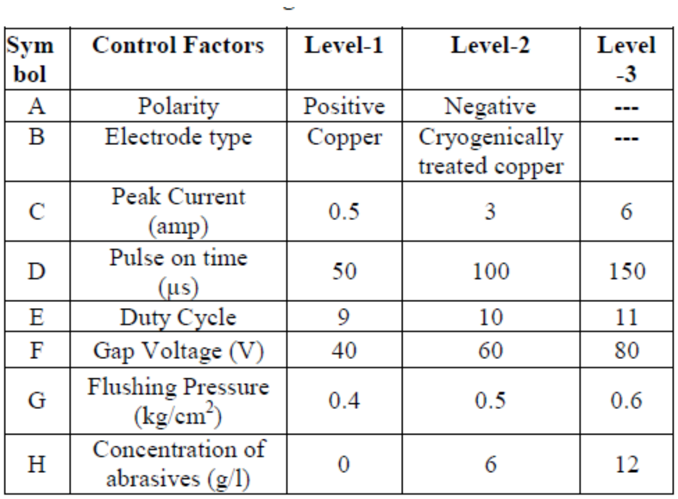
gap size between tool electrode and work piece. This leads to early discharging in spark gap and hence increased MRR. The added abrasives also change the shape of plasma channel. The widening and enlarging of channel carries more uniform discharge energy among powder particles. This produces shallow craters and hence improvement of surface finish. Narumiya H., et al. [7] reported better surface finish by suspending aluminium and graphite powders than silicon powders in dielectric fluid. Ming Q.Y., et al. [8] reported the reduction in surface roughness, reduction in tool wear rate and improvement in machining rate by the addition of additives in dielectric fluid. Kansal H.K., et al. [9] investigate the effect of silicon powder mixed into the dielectric fluid of EDM on machining characteristics of AISI D2 steel and reported the appreciably enhancement of material removal rate. Beri N. et al. [10], with the help of Taguchi method, attempted to correlate the usefulness of electrodes made through powder metallurgy in comparison with conventional copper electrode during electric discharge machining of AISID2 steel and found that electrode material, current and duty cycle has significant effect on material removal rate and surface roughness and further proved that Cu electrode is better for higher MRR and CuW electrode gives minimum surface roughness. Kumar A., et al. [11] found optimal process parameters of AEDM using Taguchi methodology. They investigations shown that with addition of silicon abrasive powder (2 g/lt) in kerosene dielectric fluid, material removal rate improves by 23% and surface roughness is reduced by 35 %. Singh P. et al. [12-13] studied the effect of concentration and grain size of aluminium powder mixed in the dielectric fluid of EDM on the machining characteristics of Hastelloy steel and reported that addition of aluminium powder in dielectric fluid increases MRR decreases TWR and improves surface finish of Hastelloy. They further studied the effect of electrical parameters (Peak current, gap voltage, pulse on time and duty cycle) in PMEDM of Hastelloy steel and reported that all these parameters strongly affects MRR, TWR, WR and SR of the process.

From the reviewed literature, it is observed that many researchers have focused their studies on MRR, SR and tool wear and material characterization. Specific studies related to dimensional accuracies are lacking. The present research study is focused on AEDM of Hastelloy steel to investigate the influence polarity, cryogenically treated electrode, peak current, pulse on time, duty cycle, gap voltage, flushing pressure and abrasive concentration in dielectric fluid on the dimensional accuracy of the process. Cryogenically treatment to the electrode material in AEDM is a new advancement to cause beneficial changes in the material properties. The advantages of cryogenic treatment include relieved residual stresses, refinement of grain sizes and better electrical and thermal properties [14-15].

2 EXPERIMENTAL PLANNING

Taguchi method which makes the use of special orthogonal arrays was used to design the experiments. The effects of several input machining parameters can be determined effectively by carrying out matrix experiments based on Taguchi's orthogonal design. In the present study total eight machining parameters viz polarity, type of electrode, peak current, pulse on time, duty cycle, gap voltage, flushing pressure and concentration of abrasives in dielectric fluid are involved to study dimensional accuracy (overcut). These input machining parameters and their levels selected for the study are tabulated in Table 1 based on trial and preliminary experimentations. Out of these eight factors, polarity and type of electrode varied at two levels. Other six factors i.e peak current, pulse on time, duty cycle, gap voltage, flushing pressure and concentration of abrasive varied at three levels. It was decided to neglect the interaction effects of these machining parameters. Total degrees of freedom are 14. Standard L_{36} orthogonal array is selected for experimentation. One machining parameter was assigned to each column. Total 36 rows represent parametric combination (in terms of levels) for each experiment.

TABLE 1
MACHINING PARAMETERS AND THEIR LEVELS



Symbol	Control Factors	Level-1	Level-2	Level -3
A	Polarity	Positive	Negative	---
B	Electrode type	Copper	Cryogenically treated copper	---
C	Peak Current (amp)	0.5	3	6
D	Pulse on time (µs)	50	100	150
E	Duty Cycle	9	10	11
F	Gap Voltage (V)	40	60	80
G	Flushing Pressure (kg/cm^2)	0.4	0.5	0.6
H	Concentration of abrasives (g/l)	0	6	12

2.1 Experimental Procedures

Experiments were performed on Electronica make standard EDM machine tool; model smart ZNC. Hastelloy steel (specimen 80mm x 45mm x 10mm) was used as work piece material and two cylindrical copper rods (one is cryogenically treated) with 8mm diameter are used as tool electrodes for conducting the experiments. To avoid wastage of dielectric fluid because of mixing of abrasive powders in it which may clog the filters of machine tool, Dielectric tank was modified by a 6 liters capacity machining tank. A rectangular piece of magnet was placed in machining tank to collect the debris produced during experimentation. A small stirring system and a dielectric circulation pump were used in machining tank to ensure uniform distribution of abrasive particles in dielectric circulation system. After every experiment the work piece was properly cleaned to measure the diameter of cavity. Four readings of diameter were taken for each hole and the average value is taken as diameter of cavity for analysis. The overcut was taken as the difference of cavity diameter and electrode diameter.

3 RESULTS AND DISCUSSIONS

Taguchi methodology has been used for the design and analysis of the experiment. Lower response characteristics i.e. OC is desirable, so selected response characteristic in the present work is overcut and will be considered as 'lower the better'

Minitab 14.1 software is employed for mean effect plots for means of response parameter i.e OC. Plots with the large slope along with longer lines shows that the factor has significant effect on response parameter (Figure 2). ANOVA analysis along with response tables are used to summarize the experimental results and to see the significance of input machining parameters on response parameter. The ANOVA (Analysis of variance) for Means for OC (lower is better) is shown in Table 2 which is clearly indicates that abrasive concentration in dielectric fluid, Polarity, electrode type and peak current are the most influencing factors whereas pulse on time, duty cycle, gap voltage and flushing pressure are relatively less influencing factors to OC. Response tables are drawn in Table 3 which gives order of importance of variable input parameters on quality characteristics. The effect plots for means for OC clearly indicates that OC is minimum at 2nd level of polarity, 1st level of electrode type, 1st level of peak current, 1st level of pulse on time, 1st level of duty cycle, 1st level of gap voltage, 1st level of flushing pressure and 1st level of abrasive concentration. From the response table and the rank assigned to various input machining parameters it is observed that concentration of abrasives, Peak current, polarity and electrode type are the main significant effective factors to OC. Rest all the factors have less influence on OC. Moreover the abrasive concentration in dielectric fluid is the most influencing factor for OC.

OC is more when conducting the experiments at positive polarity than OC at negative polarity. Sparking at the bottom of tool is always associated with side sparking on the edges of tool. In positive polarity, small mass electrons and abrasive particles strike the side walls of cavity with high velocity and heavy momentum cause more erosion of material along side walls of cavity. This increases the diameter of cavity. However, in the negative polarity, heavy mass positive ions and abrasive particles strike the side walls of cavity with less momentum and erodes less material from side walls and hence lesser is OC.

Over cutting with cryogenically treated copper tool electrode is more than untreated copper electrode. This may be due to the reason that more amount of current flows in cryogenically treated electrode due to its reduced electrical resistance. More amount of current produces more powerful side sparking which erodes more material from side walls of cavity. So although cryogenically treated electrode improves material removal rate and surface finish [12-13] but leads to less dimensional accuracy.

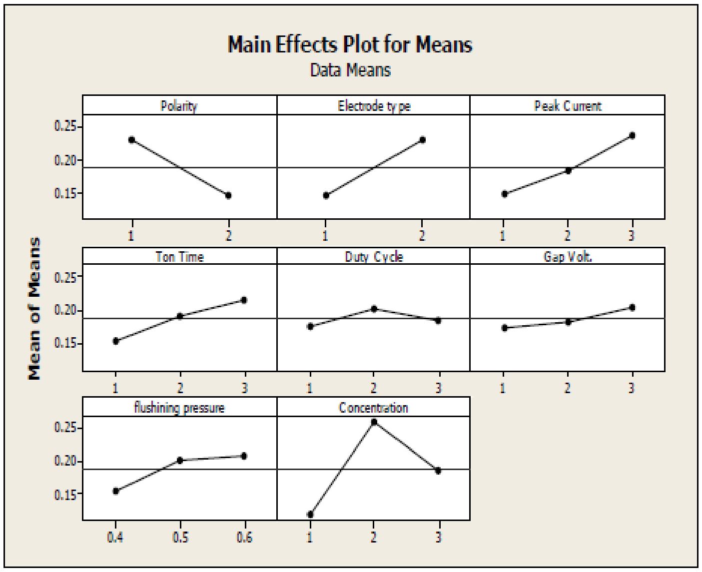


Fig.: 2 Main Effect Plots for OC ('lower the better')

TABLE 2
ANOVA FOR MEANS FOR OC (LOWER THE BETTER)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Polarity	1	0.064178	0.064178	0.064178	13.20	0.002
Electrode type	1	0.062500	0.062500	0.062500	12.86	0.002
Peak Current	2	0.047489	0.047489	0.023744	4.88	0.018
Pulse on Time	2	0.023089	0.023089	0.011544	2.37	0.118
Duty Cycle	2	0.004406	0.004406	0.002203	0.45	0.642
Gap Volt.	2	0.006206	0.006206	0.003103	0.64	0.538
Flushing Pressure	2	0.019606	0.019606	0.009803	2.02	0.158
Concentration	2	0.119072	0.119072	0.059536	12.25	0.000
Residual Error	21	0.102078	0.102078	0.004861		
Total	35	0.448622				

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TABLE 3
RESPONSE TABLE FOR MEANS FOR OC

Level	Polarity	Electrode type	Peak Current	Pulse on Time	Duty Cycle	Gap Volt.	Flushing Pressure	Concentration of abrasives
1	0.2300	0.1461	0.1467	0.1550	0.1758	0.1750	0.1550	0.1183
2	0.1456	0.2294	0.1817	0.1917	0.2025	0.1825	0.2008	0.2592
3	------	------	0.2350	0.2167	0.1850	0.2058	0.2075	0.1858
Delta	0.0844	0.0833	0.0883	0.0617	0.0267	0.0308	0.0525	0.1408
Rank	3	4	2	5	8	7	6	1

At low current values, negligible side sparking occurs hence the diameter of cavity exceeds a little than the diameter of tool electrode. With the addition of aluminium abrasives into the dielectric fluid the OC increases. This may be because of abrasive particles concentration enlarges and widens the spark gap size. The powder particles come in the path of flow of ions and move with the ions to hit and remove more material from sidewalls of cavity leading to side sparking.

4 CONFIRMATION EXPERIMENTS

As given by the main effect plots for means, $A_2B_1C_1D_1E_1F_1G_1H_1$ (Table 4) is the optimized machining parameter combination yielding minimum OC.

Table 5 shows the values of machining parameters at this optimized combination. At this parametric combination the predicted value of OC given by Minitab software is 0.007 mm. Since the optimal AEDM process machining parameter set is obtained, the confirmation tests are conducted to verify the OC value. The results of confirmation experiment are compared with the predicted value of OC as shown in Table 5. It is observed that the error between the predicted value and actual value is small (within 10%). This is the experimental error. This confirms the reproducibility of experimental conclusions.

TABLE 4
OPTIMIZED INPUT MACHINING PARAMETERS

Polarity	Negative
Electrode type	Untreated copper
Peak current	0.5
Pulse on time (μs)	50
Duty cycle	9
Gap voltage (volt)	40
Flushing pressure (kg/cm^2)	0.4
Concentration (g/lt)	0

TABLE 4
CONFIRMATION TEST

Response	**Confirmation Experimen**	**Predicted**	**Actual**	**Error %**
OC (mm)	1	0.007	0.00743	6.15
	2	0.007	0.00751	7.31
	3	0.007	0.00752	7.54

5 CONCLUSION

This study has investigated the influence of various input machining parameters during AEDM process. On the basis of results obtained, following conclusions can be drawn in the investigated range:

1. The Taguchi approach employed enabled the identification of significant factors and their associated influence levels on OC.
2. All the selected input machining parameters influence the dimensional accuracy of the process.
3. Concentration of abrasives in dielectric fluid, Peak current, polarity and electrode type are the main significant effective factors to OC. Rest all the factors have less influence on OC. Moreover the abrasive concentration in dielectric fluid is the most influencing factor for OC.
4. By optimizing the machining parameters the overcut is minimized which enhances the quality of machining process. The results are proved by confirmation tests.

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