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Effect of Process Parameters on Machining Performances during Machining of Al7075-T6 in Electro-Discharge Machining

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Abstract*:*In the present study, the machining of Al7075-T6 has been carried out in Electro-discharge machining(EDM) process. Taguchi L_9 orthogonal array is used to conduct the experiments with three levels of process parameters.The effect of process parameter like spark gap and pulse off time on the machining performances have been analyzed. The machining performances such as material removal rate (MRR) and tool wear rate (TWR) have been analyzed for both the stationary and rotary tool EDM. Moreover, surface morphology has been studied in both the machining environment. It has been found that MRR is more in the case of rotary tool EDM as compared to stationary tool EDM.

Keywords:Taguchi Method, ANOVA, Surface topography

I. INTRODUCTION

Now-a-days, researcher are opting for machining on various non- traditional machining processes as it provides high dimensional accuracy and good surface finish. Out of the various non-traditional machining processes, Electro-discharge machining (EDM) is one of the technology which is widely used in die-making industry.This process includes a series of repeated discharges created by electric pulse generator between two electrodes in short intervals of time. The surface temperature of both the tool and work piece raises to a point more than melting point of metal due to the electric spark generates in working zone. Due to this high temperature, material is mainly removed in the liquid and vapor phases. The eroded particles from the working zone flushes away by the pressurized dielectric fluid. EDM finds its vast application on machining of high strength material as mechanical properties doesn't influence its machining performance. Basically, Aluminum alloy Al7075-T6 is lighter in weight and high in strength. Due to its high strength, it finds its vast application in making arms and ammunitions. Many researchers are investigated the effect of process parameters on machining performance in electro-discharge machining. Few of them are cited here to represent for further research.Aliakbari*et al.* has conducted the optimization of machining parameters in rotary EDM by

utilizing the Taguchi approach and has concluded that the rotary EDM tool has an electrical base; the electrical parameters are more compelling than the nonelectric parameters on the yields [1]. Malak*et al.* has performed a comparative study of EDM with the rotary EDM machining of EN-8 and concluded that the material removal rate (MRR) increases as the speed of tool increases in rotating EDM as compare to stationary EDM [2]. Dwivedi*et al.* has conducted an experiment on surface roughness of AISI D3 tool steel by rotary EDM and concluded that the rotary tool EDM gives a better surface finish values as the rotation in the tool enables uniform work piece machining [3]. Singh *et al.* tried to know the impact of T_{off}/T_{on} on EDM of AISI D3 utilizing copper and brass tool in EDM and has concluded that material removal rate is increases with increasein pulse off time and diminishes with increase in pulse on time[4]. Surface finishof AISI D3 is increases due to the tool rotation in EDM process. Surface roughness, recast layer and micro-cracks are studied and found that surface finish increases, micro-cracks decreases and recast layers decreases as compared to EDM process with stationary tool [5]. Minimum quantity lubrication method is adopted in EDM process where a very little amount of dielectric mixed with air and flushes the working zone during the machining of EN-8. Moreover, the process parameters are taken as tool rotating speed, gap voltage, current, and pulse on time for machining. It found that current and pulse on time take the prominent factor for deciding the roughness parameters [6]. Pushyanth*et al.* has conducted an investigation on surface finish analysis of AISI-D7 using EDM and concluded that MRR is mostly influences by pulse-off-time (T_{off}) and feed rate (mm/min). Comparatively, the effect of pulse-on-time (T_{on}) is less on MRR [7]. Pandey *et al.* [8] had studied rotary copper-tool (cryogenically treated) electrode EDM and cited that metal removal improves with less wear and high surface quality. Anand*et al.* [9-10] conducted an experiment on optimization of input parameters in EDM with magnetic field and concluded that magnetic effect in magnetic base of EDM increases 41.42 % MRR and surface roughness reducesby 2.17 %.

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Although many papers exhibit about the different process parameters and their effect on responses but very less paper are there which shows the effect of the spark gap on responses i.e. MRR and TWR. There are less paper exhibiting the use of Al7075-T6 alloy on EDM machining as the material is emerging very rapidly in industry especially in the field of aviation and automobile.

In this research work, a comparative study of machining performance of Al7075 -T6 alloy on rotary and stationary tool EDM has been discussed. Furthermore, it has been verified which EDM process satisfies the industry demand efficiently and elaborated the effect of spark gap and pulse off time (T_{off}) on material removal and tool wear rate.

II. EXPERIMENTAL DETAILS

A series of experiment on Al7075-T6 alloy has been performed on stationary and rotary tool EDM. Agiecharmiles FORM E-350 and Agiecharmiles FORM S-350 have been used to machine the work pieces in stationary and rotary tool machining condition respectively. In both the machining condition, kerosene is used as the dielectric fluid.

A. Work Materials

The work-piece material is used as Al7075-T6 alloy having composition of Si 0.22%, Fe 0.15%, Cu 1.5%, Mn0.13%, Mg 2.4%, Cr 0.14%, Zn 5.5%, Ti 0.02%, B 0.05%, Bi0.05%, Pb0.08%, Sn 0.02%, V 0.013%, Zr 0.013% and Al 89.98%. The physical property of Al7075-T6 alloy is as follows: Density 2.81gm/cc, Melting point 660 ^{o}C, Hardness 53.5HRA, Ultimate tensile strength 571.53 MPa and Thermal conductivity 130 W/m-K.The size of each work piece is about 100mm x 45mm x 10mm.

B. Tool Material

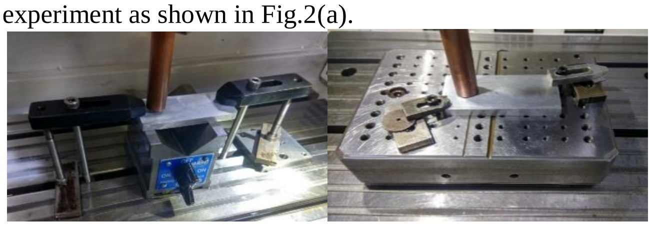
Electrolytic copper having 99% of copper is selected as the tool electrode having the physical properties as follows: density 8.9 gm/cc, melting point 1085 ^{o}C and electrical resistivity 9 µΩ cm. The diameter of the electrode is about 19mm as shown in Fig.1.

Fig.1 Electrode used in experiment

C. Quality Check

Stationary tool electrical discharge machining

The Agiecharmiles FORM E-350 is a die sinking machine manufactured by GF machining solutions, Switzerland. The tool electrode is connected with negative tool polarity whereas the workpiece is connected with positive polarity. A fixture was used to handle the work material throughout the experiment as shown in Fig.2(a).



(a) (b)

Fig.2 Fixture used for (a) stationary EDM(b) rotary EDM

Rotary tool electrical discharge machining

The Agiecharmiles FORM S-350 is a die sinking electro-discharge machine manufactured by GF machining solutions, Switzerland. In this case, the tool also connected with negative polarity. The tool rotation was fixed at100 rpm for all set of experiments. A fixture was used to handle the work material as shown in Fig.2(b).

III. RESULT AND DISCUSSIONS

In this experimentation, two factors with three levels were selected. Taguchi method is used in this design of experiment (DOE) which proposes L_9 orthogonal array which comprises of nine set of experiments. The same factors with similar levels are selected for both stationary and rotary EDM. The process parameters with their levels and layout are shown in Table I and Table II respectively.

Table I Level of input parameters

Factors	Symbols	Levels		
		1	2	3
Spark gap(mm)	A	0.2	0.3	0.4
Pulse off time (µs)	B	30	50	70

Table II Coded and Actual value of process variables

Experiment no:	Spark gap	Pulse off time	Spark gap (mm)	Pulse off time(µs)
1	1	1	0.2	30
2	1	2	0.2	50
3	1	3	0.2	70
4	2	1	0.3	30
5	2	2	0.3	50
6	2	3	0.3	70
7	3	1	0.4	30
8	3	2	0.4	50
9	3	3	0.4	70

During the experiment, both work piece and tool weight are measured before and after each set of experiment for both the stationary and rotary tool EDM. After the experiment the MRR and TWR were calculated. Fig. 3(a) represents the work piece after machining in rotary tool EDM whereas Fig. 3(b) represents after machining in stationary EDM process.

(a) (b)

Fig. 3. Al7075-T6 after machining in (a)stationary EDM (b) rotary tool EDM

Table III Experimental results of rotary tool EDM

Experiment no.	MRR (mm3/min)	TWR(mm3/min)
1	0.03769	0.00236
2	0.03729	0.00129
3	0.03579	0.00103
4	0.05462	0.0025
5	0.04641	0.00137
6	0.04070	0.00220
7	0.05610	0.00268
8	0.05322	0.00141
9	0.04865	0.00180

Table IV Experimental results of stationary tool EDM

Experiment no.	MRR (mm3/min)	TWR (mm3/min)
1	0.03409	0.00239
2	0.03558	0.00101

3	0.02729	0.00064
4	0.04723	0.00248
5	0.04151	0.00147
6	0.02802	0.00184
7	0.04875	0.00254
8	0.04448	0.00133
9	0.03992	0.00132

Graphical representation of MRR in stationary and rotary tool EDM

As shown in the Fig. 4, the variation of material removal rate in series of experiments have been increased significantly with comparison to rotary tool EDM and stationary tool EDM due to the fact that tool rotation clears the molten metal from the crater more effectively and efficiently thus exposing the clear surface during each spark cycle.

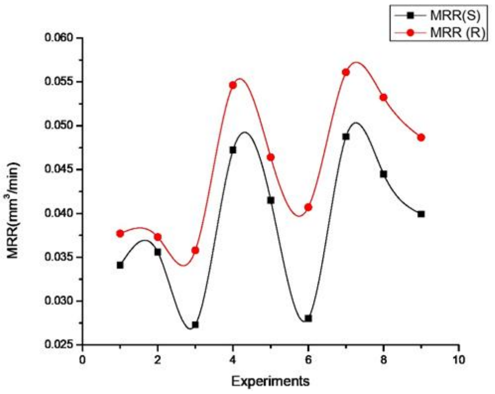


Fig. 4 Variation of MRR in different set of experiments in stationary and rotary tool EDM

Graphical representation of Tool wear rate in stationary and rotary tool EDM

Fig.5 shows that, TWR significantly increases in rotary tool EDM machining due to the fact that rotation of tool increases the spark intensity which in turn increases the melting process due to the abundance of spark.

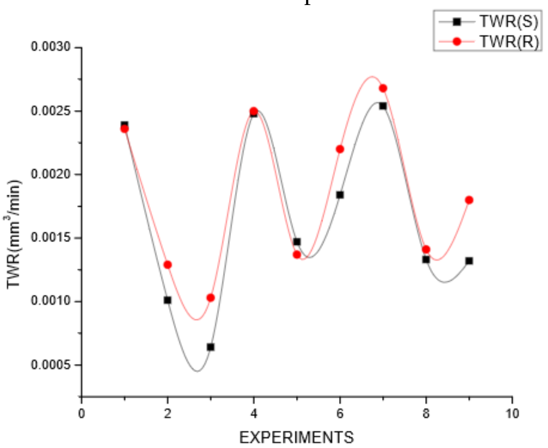


Fig. 5 Variation of TWR in rotary and stationary tool EDM

Determination of significant process parameter for MRR in rotary tool EDM

The S/N ratio for MRR in rotary EDM is find out with consideration of larger is better characteristics as per equation (1) where y stands for MRR of i^{th}number of run.

The S/N ratio (in dB) obtained by

$$\text{S/N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right) \quad (1)$$

The mean S/N ratio is summarized in a Table V. The main effect plot is shown in Fig.6. The optimized combination of process parameter is A_3-B_1. Therefore, the significant process parameter for MRR is as follows: Spark gap at 0.4 mm and pulse off time is at 30 micro-second.

Table V Mean S/N ratio table for MRR in rotary EDM

Level	Spark gap	T_{off}
1	-28.66	-26.25
2	-26.58	-26.90
3	-25.59	-27.66
Delta	3.07	1.41
Rank	1	2

Total mean S/N ratio: -26.94

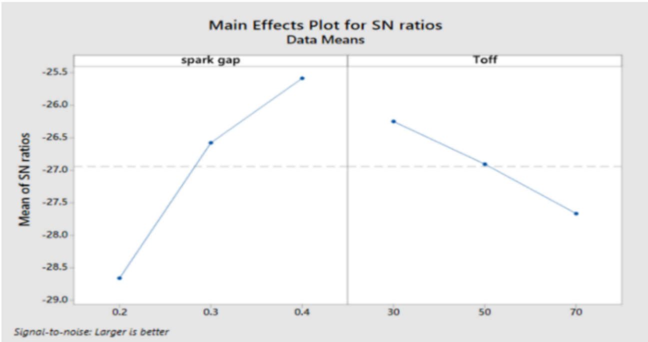


Fig.6 Main effect plot for S/N ratio for MRR in rotary EDM

Analysis of variance (ANOVA) is find out for the significance of process parameter on responses. It is found that P-value for spark gap is less than 0.05 which imply that the spark gap is significance at 95% of confidence level for MRR in rotary EDM. A confirmation test has been carried out for predict and verify the improvement of the responseswith optimum set of process parameter as shown in Table VI.

Table VI Confirmation test on MRR

	Initial parameter	Significant parameter	
		Predictions	Experiment
level	A_1B_1	A_3B_1	A_3B_1
MRR	0.03769		0.0561
S/N Ratio	-28.4755	-24.8962	-25.0207
Improvement of S/N ratio = 3.4548			

Regression equation for MRR.

A regression equation is an empirical model of the factors associated with the responses. It is basically a type of interpolation equation for the responses variable. The regression equation (2) for MRR was found out to be:

$$\text{MRR} = 0.0006 + 0.261A + 0.000026B - 0.245A^2 - 0.0B^2 - 0.000694AB \quad (2)$$

Determination of optimal process parameter for TWR in rotary EDM

The S/N ratio for TWR was found out considering smaller the better characteristics (in dB) is

$$\text{S/N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y^2\right) \quad (3)$$

where Y is the value of TWR for the ithno of experiment.

Main effect plot for TWR is shown in Fig.7. The optimized combination of process parameter is A_1-B_2.

Therefore, the significant process parameter for TWR is as follows: Spark gap at 0.2 mm and pulse off time is at 50 µs. The mean S/N ratio is summarized in Table VII.

Table VII Mean S/N ratio table for TWR

Level	Spark gap	T_{off}
1	56.69	52.01
2	54.15	57.36
3	54.45	55.93
Delta	2.54	5.35
Rank	2	1

Total mean S/N ratio = 55.0967

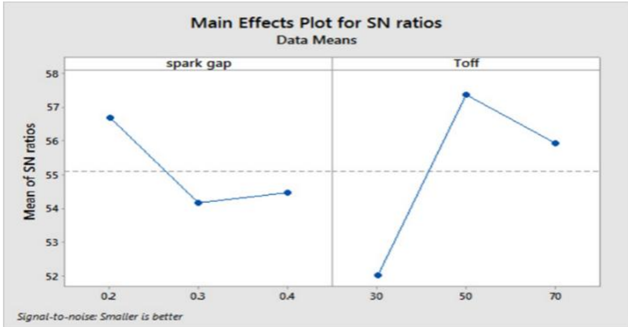


Fig.7 Main effect plot for S/N ratio for TWR

The ANOVA for TWR has been found and P-value of pulse of time is less than 0.05 which imply the significance for TWR in rotary EDM. In the confirmation test, the improvement of TWRshown in Table VIII.

Table VIII Confirmation test on TWR

	Initial parameter	Significant parameter	
		Predictions	Experiment
level	A_1B_1	A_2B_1	A_2B_1
MRR	0.00236		0.0025
S/N Ratio (dB)	52.54176	51.0619	52.0412
Improvement of S/N ratio = 0.5005			

Regression equation for TWR

The regression equation for TWR was found out to be

$$TWR = 0.00508 + 0.0149A - 0.000222B - 0.0262A^2 + 0.000002B^2 + 0.000056AB \quad (14)$$

Similarly, the MRR and TWR in stationary tool EDM have been analyzed. The optimal combination of process parameter for MRR is A_3-B_1 i.e. spark gap of 0.4mm and pulse off time of 30 µs. For the TWR, the combination process parameter is A1-B3 i.e. spark gap of 0.2mm and pulse off time 70 µs.

ANALYSIS OF SURFACE INTEGRITY

The machined work piece has been studied on the scanning electron microscope. The scanning electron microscope used was ZEISS-SUPRA 55 show in Fig. 8 which is manufactured by Carl Zeiss a German brand.

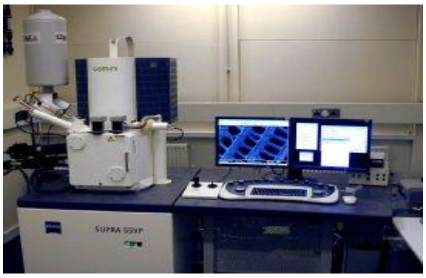


Fig.8 Scanning electron microscope used for micrograph

Surface topography of the machined surface

SEM micrographs have been taken in the optimized condition of process parameter in both rotary and stationary EDM process. It has been seen that surface texture in rotary tool EDMed machine was smoother than that of stationary tool EDMed surface as shown in Fig.9 and Fig. 10. Furthermore, it has been observed that stationary tool EDM has a greater crater size as compared to rotary tool EDM because debris of spark area is effectively cleaned.

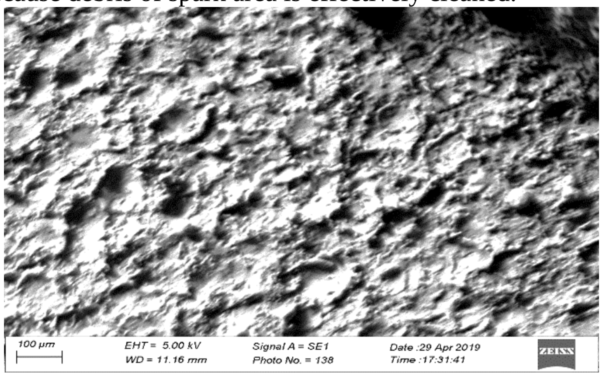


Fig.9 Scanning electron microscope showing rotary tool EDMed work piece at spark gap-0.4mm and pulse off time-30µs

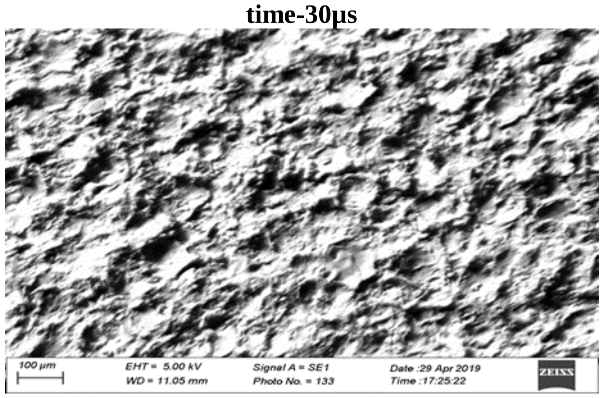


Fig.10 Scanning electron microscope showing stationary tool EDMed work piece at spark gap-0.4mm and pulse off time-30µs

IV. CONCLUSIONS

The experiments are conducted on electro-discharge machining of Al7075-T6 alloy in both rotary and stationary mode, and the following conclusions have been drawn.

- For material removal from the workpiece, the spark gap was most significant process parameter for material removal rate in rotary EDM as well as stationary EDM and the level setting of MRR was spark gap at 0.4mm and pulse off time at 30µs (A_3B_1) in both rotary & stationary tool EDM.
- For TWR the pulse off time was the most significant parameter in Rotary & stationary EDM. The optimized setting process parameter for TWR is spark gap at 0.3mm and pulse off time at 30µs (A_2B_1) for both rotary & stationary EDM.
- It has been concluded that the stationary tooled EDM has greater crater size as compared to rotary EDM.
- Finally, it concludes that electro-discharge machining of Al7075-T6 alloy in rotary tool EDM is more suitable in order to obtain high MRR and low TWR.

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