EXPERIMENTAL EVALUATION OF PERFORMANCE OF ELECTRICAL DISCHARGE MACHINING OF D3 DIE STEEL WITH Al_2O_3 ABRASIVE MIXED DIELECTRIC MATERIAL BY USING DESIGN OF EXPERIMENTS

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Abstract

Electrical discharge machining is the most widely used machining process in industries. Its use is particularly intense when very complex shapes on hard materials with a high dimensional accuracy are required. However the technological capability of the process has limited application when there is a requirement of high surface quality and mirror like characteristics. Its operation is characterized by long machining time, high tool wear and uncertainty in the final finish of the surface. However for finish surface, materials are subjected to mechanical polishing after EDM, which is wastage of time and energy. To improve the efficiency and surface finish of the work piece, the abrasive particles of Aluminum oxide (Al_2O_3) are mixed into the dielectric fluid at tool-work interface. In this Abrasive mixed EDM, the Abrasive mixed dielectric fluid facilitate the bridging effect and minimize the insulating strength of the dielectric fluid. As a result it improves the material removal rate and surface roughness. This paper presents the effect of abrasive on the performance of the EDM process. The results of both the processes have been analyzed using Design of experiments to find the significant parameters and to obtain the optimum parameters required for machining.

Analyzed results indicate that abrasive particle size and abrasive concentration and pulse current are the most significant parameters that improve the material removal rate in comparison with traditional EDM. A new experimental setup is developed for experimentation. The result shows that the MRR increases with the abrasive mixed EDM.

***Keywords**: Material removal rate, Abrasive mixed EDM, Dielectric fluid, Design of experiment, Abrasive particle size.*

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1. INTRODUCTION

Electrical discharge machining is one of the widely used non-conventional machining process. Advancement in material science over the recent years has forced the development of advanced materials having better mechanical properties. Advanced materials like Die steel, super alloys are the key materials having wide spread industrial applications. It can be successfully employed to machine electrically conductive parts regardless of their hardness and toughness. However the technology capability of the process has limited application when there is a requirement of High metal removal and High surface quality.

The EDM is such a manufacturing process for the tool, mould and die industries for several decades. It has the capability to machine very hard materials and to produce complicated profiles. The abrasive particles of Aluminum oxide (Al_2O_3) are mixed into the dielectric fluid of EDM. These current conducting particles cause electric field aberration in the discharge gap. The positive and negative charges gather at the top and bottom of the abrasive particles. Near the abrasive particles the electric filed density is the highest, discharge breakdown at the beginning will occur when the electrical filed density surpasses the breakdown resistant capability. Discharge breakdown then causes a short circuit between the two abrasive particles and the redistribution of electric charges. The electric charges then leads to the discharge between two abrasive particles and other abrasive particles resulting in series discharge and accordingly the discharge breakdown between the electrode and the work piece. Thus it has been found that the addition of abrasive particles widens the discharge gap thus decreasing the gap voltage and insulation strength of the dielectric fluid. The enlarged discharge passage also increases the discharge heat area and reduces the discharge density. This leads to formation of evenly distributed large diameter and shallow craters. Thus subsequently improving the surface finish. Thus abrasive mixed EDM generally reduces the thermal stress and tendency to cracking. The machined surface of the work piece reveals more uniform surface with les cracks requiring no grinding operation and the part can be utilized directly.

2. LITERATURE REVIEW

The brief summary of the review of the available Literature is given. Kuang- yuan kung Jenn-Tsong Horng investigated the effects of powder mixed electrical discharge machining of Cobalt-bounded tungsten carbide with different grain sizes and different concentrations of Aluminum powder particles suspended in the dielectric fluid. The MRR increases with an increase of aluminum powder concentration after a certain limit the aluminum powder concentration leads to decrease in MRR and tool wear rate. Both MRR & TWR increases with increase of the grain size.

Tzing.Y.F and Lee.C.F reported the investigations of powder mixed EDM on SKD11 material using kerosene-mixed with Aluminum, Chromium, copper additives, significant improvements in the material removal and improving the resistance of machined surface from corrosion and abrasion. Yan.B.H and chen.S.L_investigated the effect of suspended aluminum and silicon carbide powders and found that there is considerable improvement in MRR.

H. Narumiya_investigated the effects of powder in dielectric fluid on material removal rate and surface roughness. It was reported that aluminum and graphite powders in the dielectric yield better surface than the silicon powder. The improved results are found for aluminum and graphite powder particles. M.N. Mohri, N.Saito carried out work by mixing Silicon powder into the dielectric of the EDM process and obtained very fine surface finish by mixing the Silicon powder of 10-30 µm particle size. However they have not studied the effect of Silicon powder on material removal rate. Q.Y.Ming, L.Y.Hee have observed the effects of powder mixed in the dielectric fluid for EDM. In the middle-rough machining the MRR can be increased by about 50% and surface roughness Ra = 4-5 µm. In the middle-finish machining the MRR can be doubled and surface roughness Ra = 2-3 µm.

P. Pecas and E.A. Henriques_carried out the work on Silicon powder mixed dielectric on EDM. They observed that by addition of 2g/lit of silicon powder the operating time and surface roughness decreases.

G.S.Prihandana, M.Hamdi, Y.S.Wong investigated the effect of nanographite powder in dielectric fluid and found that improvement in MRR and reduction in machining time as well as improvement in surface quality by eliminating the micro-cracks in the surface.

Han-Ming Chow, Lieh-Dai Yang carried out work by mixing Sic powder in water as dielectric for Micro-Slit EDM and found that Sic powder would increase working fluid electrical conductivity and enlarge the electrode and work piece gap, therefore material removal rate is increased.

M.L.Jeswani carried out the work by mixing the graphite powder into kerosene oil dielectric on EDM. He observed that addition of graphite powder increases the interspace for electric discharge initiation and improvement in machining process stability.

Literature Review reveals that, the work has been carried out by mixing the different metal powders in dielectric fluid. In this paper the influence of abrasive (Al_2O_3) on $D_{3\ Die}$ steel has been made to obtain an optimal setting for Material removal rate in abrasive mixed Electrical discharge machining. Design of experiments had been used to plan and analyze the results.

3. EXPERIMENTATION

Experiments were conducted on ZPNC - 480 EDM Machine. The existing work tank of the Machine require huge amount of dielectric fluid for flushing. Therefore the new system is developed for the circulation of abrasive mixed dielectric fluid. The schematic diagram of new developed system is shown in fig1. The new abrasive circulation system is designed for 5 liters of dielectric fluid.

The new abrasive mixed dielectric circulation system consists of a container called machining tank. This container is placed in the main dielectric tank of EDM and machining is carried out. The work piece is fixed on a fixture assembly for machining. A stirring system is developed to avoid the abrasive particle settling at the bottom of the tank.

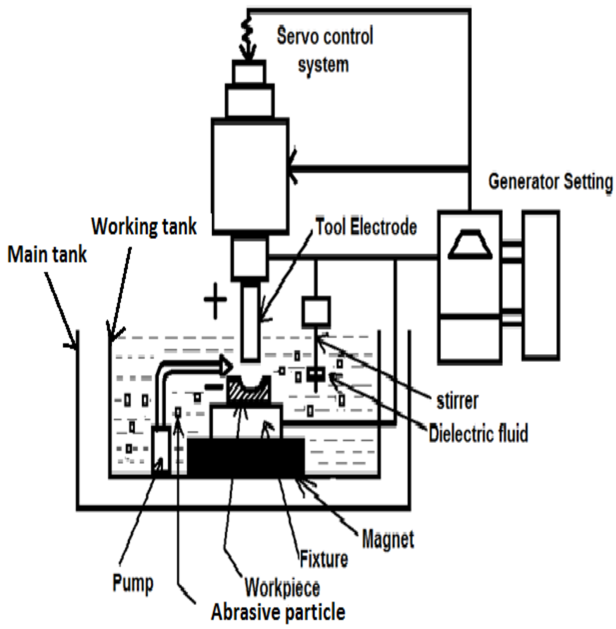

Fig 1 Schematic diagram of AMEDM Experimental setup

The input parameters discharge current, pulse on time, duty cycle, gains were set for each experiment, Polarity, Nozzle flushing was taken as per the requirement. These values were taken as per the design of experiment obtained from L_{18} orthogonal array as given in table3.

(a)

(b)

Fig 2: a & b: Photographs of Workpieces Machined by AMEDM

Experiments were carried out on a general EDM and by adding abrasive as Al_2O_3 to dielectric fluid, where the abrasive particles are re-circulated during the experiment for reuse. MRR for each run was calculated on the basis of weight difference before and after the machining using electronic weighing machine.

3.1 Work Material

AISI D_3 Die steel was selected as work material to carryout the experiment, D_3 die steel is an air hardening high carbon high chromium tool steel. It displays excellent abrasion & wear resistance. It is heat treatable and will offer a hardness in the rage 58-64 HRC. It is used in manufacturing of blanking tools, thread rolling dies, drawing dies and pressing tools for the ceramics & cold rolls for multiple roller strands.

Table 1- Chemical composition of AISI D3 Die Steel

Elements	**C**	**Si**	**Cr**	**Mn**
%	**2.10**	**0.30**	**11.50**	**0.40**

4. DESIGN OF EXPERIMENTS

All the experiments were designed based on design of experiments. It includes the selection of parameters and their levels of the abrasive mixed EDM process. In this study seven processing parameters were selected, comprising six control factors at three levels each and one noise factor at two levels for abrasive mixed EDM and five processing parameters are selected for traditional EDM, comprising four control factors at three levels each and one noise factor at two levels.

The orthogonal array selected is based on the degree of freedom of process parameters. The L18 (2^1 x 3^6) orthogonal array is transformed to S/N ratio of the response parameter by using Mini-Tab software. The variation of mean value of response parameter levels of input parameters is obtained. The OA is selected on the basis of condition that the degree of freedom for the OA should be greater than or equal to that of the process parameters.

4.1 Taguchi Method

Taguchi method is an experimental technique which is useful in reducing the number of experiments using orthogonal array and also tries to minimize the effects of factors out of control. The greatest advantage of Taguchi method is to decrease the experimental time, to reduce the cost and find out the significant factors in a lesser time period. It focuses on determining the parameter settings producing the best levels of a quality characteristic with minimum variations. Signal to Noise ratio is the ratio of the mean to the standard deviation. The S/N ratio depends on the criteria of the quality characteristics to be optimized. The Larger the better type of S/N ratio is used.

Larger - The- Better Type (LB)

$$\eta = S/N = -10 \log [1/n \Sigma_1^{\eta} 1/Yi^2]$$

Where,

Yi is the measured response in i^{th} run.
n= Number of observations in a row

Since Maximum Metal removal value is desirable, Larger-the- Better type of quality characteristics is used.

Analysis of variance is used to determine the statistical significance of the control parameters**.** The optimum combination of cutting parameters is determined with the help of main effect plots.

4.2 Experimental Design for Abrasive Mixed EDM:

Number of Parameters = 7

Total Degree of freedom (DOF) For 7 parameters = 7 x (3-1) = 14

Therefore minimum number of experiments = Total DOF +1 = 14 +1 = 15

Minimum No. of experiments considered are = 18

L18 (2^1 x3^6) orthogonal array of Taguchi is selected.

Table 2- Factors with codes and Levels for abrasive mixed EDM

Factor Code	Parameters	Levels		
		1	2	3
A	Nozzle flushing	Yes	No	-
B	Discharge current(Amp)	5	7.5	9
C	Duty Cycle (%)	0.6	0.7	0.8
D	Pulse on time (sec)	50	100	150
E	Abrasive Particle concentration (g/lit)	4	6	8
F	Abrasive Particle size (Grit size of abrasive)	320	400	600
G	Gain (mm/sec)	0.8	0.9	1.00

Table 3 - Factor Assignments and Experimental Results of Abrasive mixed EDM (L18 ($2^1 \times 3^6$) orthogonal array) **:**

Expt.NO	Factors							MRR mm^3/min	S/N Ratio
	A	B	C	D	E	F	G		
1	Y	5.0	0.6	50	4	320	0.8	7.10	17.0252
2	Y	5.0	0.7	100	6	400	0.9	8.90	18.9878
3	Y	5.0	0.8	150	8	600	1.0	7.95	18.0073
4	Y	7.5	0.6	50	6	400	1.0	12.15	21.6915
5	Y	7.5	0.7	100	8	600	0.8	11.90	21.5109
6	Y	7.5	0.8	150	4	320	0.9	10.80	20.6685
7	Y	9.0	0.6	100	4	600	0.9	17.80	25.0084
8	Y	9.0	0.7	150	6	320	1.0	16.81	24.5114
9	Y	9.0	0.8	50	8	400	0.8	16.20	24.1903
10	N	5.0	0.6	150	8	400	0.9	8.15	18.2232
11	N	5.0	0.7	50	4	600	1.0	8.70	18.7904
12	N	5.0	0.8	100	6	320	0.8	8.81	18.8995
13	N	7.5	0.6	100	8	320	1.0	10.80	20.6685
14	N	7.5	0.7	150	4	400	0.8	10.10	20.0864
15	N	7.5	0.8	50	6	600	0.9	11.20	20.9844
16	N	5.0	0.6	150	6	600	0.8	17.60	24.9103
17	N	5.0	0.7	50	8	320	0.9	16.50	24.3497
18	N	5.0	0.8	100	4	400	1.0	17.10	24.6599

Table 4 - Factor Assignments and Experimental Results of Conventional EDM (L18 ($2^1 \times 3^6$) orthogonal array)

Expt.NO	Factors					MRR mm^3/min	S/N Ratio
	A	B	C	D	G		
1	Y	5.0	0.6	50	0.8	3.40	10.6296
2	Y	5.0	0.7	100	0.9	5.10	14.1514
3	Y	5.0	0.8	150	1.0	4.60	13.2552
4	Y	7.5	0.6	50	0.9	7.22	17.1707
5	Y	7.5	0.7	100	1.0	7.96	18.0183
6	Y	7.5	0.8	150	0.8	6.60	16.3909
7	Y	9.0	0.6	100	0.8	10.86	20.7166
8	Y	9.0	0.7	150	0.9	9.51	19.5636
9	Y	9.0	0.8	50	1.0	10.45	20.3823
10	N	5.0	0.6	150	1.0	4.45	12.9672
11	N	5.0	0.7	50	0.8	3.66	11.2696
12	N	5.0	0.8	100	0.9	5.12	14.1854
13	N	7.5	0.6	100	1.0	7.80	17.8419
14	N	7.5	0.7	150	0.8	7.35	17.3257
15	N	7.5	0.8	50	0.9	6.20	15.8478
16	N	9.0	0.6	150	0.9	11.05	20.8672
17	N	9.0	0.7	50	1.0	9.71	19.7444
18	N	9.0	0.8	100	0.8	10.55	20.4650

5. RESULTS AND DISCUSSION:

Table 5 - Response table for Signal to Noise ratios for MRR (AMEDM): **Larger is better:**

Level	**Flushing (A)**	**Discharge Current(B)**	**Duty Cycle % C)**	**Pulse on time (D)**	**Abrasive P. conc. (E)**	**Abrasive P. Size(F)**	**Gain Mm/sec(G)**
1.	21.29	18.32	21.25	21.17	21.04	21.02	21.31
2.	21.29	20.94	21.37	21.6	21.66	21.54	21.37
3.	-	24.60	21.23	21.07	21.16	21.10	21.39
Delta	0.00	6.28	0.14	0.55	0.62	0.51	0.28
Rank	7	1	6	3	2	4	5

Table 6 - Analysis of Variance for S/N Ratio of MRR for abrasive mixed EDM:

Source	**DF**	**Seq.SS**	**Adj.SS**	**Adj.MS**	**F**	**P**
Flushing (A)	1	0.0000	0.0000	0.0000	0.00	0.992
Discharge current (B)	2	119.5367	119.5367	59.7683	156.46	0.000
Duty cycle% (C)	2	0.0667	0.0667	0.0334	0.09	0.918
Pulse on time (D)	2	1.0431	1.0431	0.5215	1.37	0.353
Abrasive.p.c (E)	2	1.3194	1.3194	0.6597	1.73	0.288
Abrasive.p.s (F)	2	0.7985	0.7985	0.3992	1.05	0.431
Gain(mm/sec)(G)	2	0.3045	0.3045	0.1522	0.40	0.695
Error	4	1.5281	1.5281	0.3820		
Total	17	124.5969				

S=0.618074 R-Sq=98.77% R-Sq(adj)=94.79%

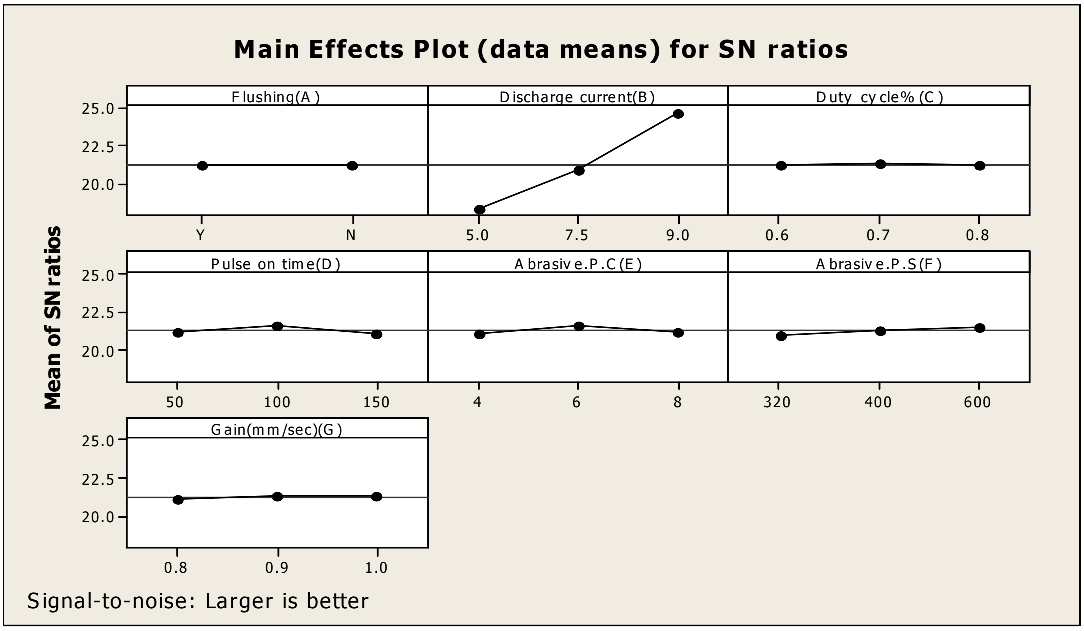

Fig. 3 Main Effects Plot (data means) for S/N ratios **for abrasive mixed EDM:**

The effects of the seven parameters on the average value of MRR and S/N rations are shown in Table 6 and this is utilized to find out their relative importance and to rank them based on the differences in the average values. The effects of parameters on the mean values of S/N ratios of each levels of control variables are plotted on the graphs shown in fig3. It is found that discharge current is the most important parameter that influence the MRR, this is because the current has a large impact on input energy fallowed by abrasive particle size, abrasive particle (Al_2O_3) concentration, pulse on time, gain and Duty cycle.

The optimum parametric combination of MRR for abrasive mixed EDM is A1B3C2D2E2F3G3 With the abrasive particle Grit size of 500 into the dielectric fluid, helps to increase the MRR in abrasive mixed EDM, thus reducing the arcing tendency. With the large abrasive particle size increases the gap between the electrode and work piece but decreases the MRR. Increasing the abrasive particle concentration in the dielectric first increases the MRR due to more erosion of work material. It is observed that the increase in gap may have wider discharge passages. The abrasive particle get energized and grains come closer to each other in the sparking area . The particles tries to bridge the discharge gap between the tool and electrode hence increases the MRR.

The optimum gap is reached at 6g/lit of Al_2O_3 concentration in the dielectric for maximum MRR. Flushing seems to have very less effect on MRR. Analysis of variance has been performed to investigate the statistical significance of parameters at 95% confidence level. The significance of each parameters was tested using probability values, when the p value in the ANOVA Table for S/N ratio is less than 0.05 for confidence level of 95% , It is considered as statistically significant. From the result of ANOVA shown in Table 6 it is found that the most significant parameter is discharge current.

Table 7 - Response Table for signal to Noise Ratio for MRR of Traditional EDM: **Larger the better:**

Level	Flushing (A)	Discharge Current (B)	Duty cycle (C)	Pulse on Time (D)	Gain (G)
1.	16.70	12.74	16.70	15.84	16.13
2.	16.72	17.10	16.68	17.56	16.96
3.	-	20.29	16.75	16.73	17.03
Delta	0.03	7.55	0.084	1.72	0.90
Rank	5	1	4	2	3

Table 8 - Analysis of Variance for S/N Ratio of MRR for traditional EDM:

Source	**DF**	**Seq.SS**	**Adj.SS**	**Adj.MS**	**F**	**P**
Flushing(A)	1	0.003	0.003	0.003	0.01	0.939
Discharge Current (B)	2	172.221	172.221	86.111	173.49	0.000
Duty Cycle (c)	2	0.018	0.018	0.009	0.02	0.982
Pulse on time (D)	2	8.902	8.902	4.451	8.97	0.009
Gain (G)	2	3.020	3.020	1.510	3.04	0.104
Error	8	3.971	3.971	0.496		
Total	17	188.136				

S=0.704512 R-Sq=97.89% R-Sq(adj)=95.52%

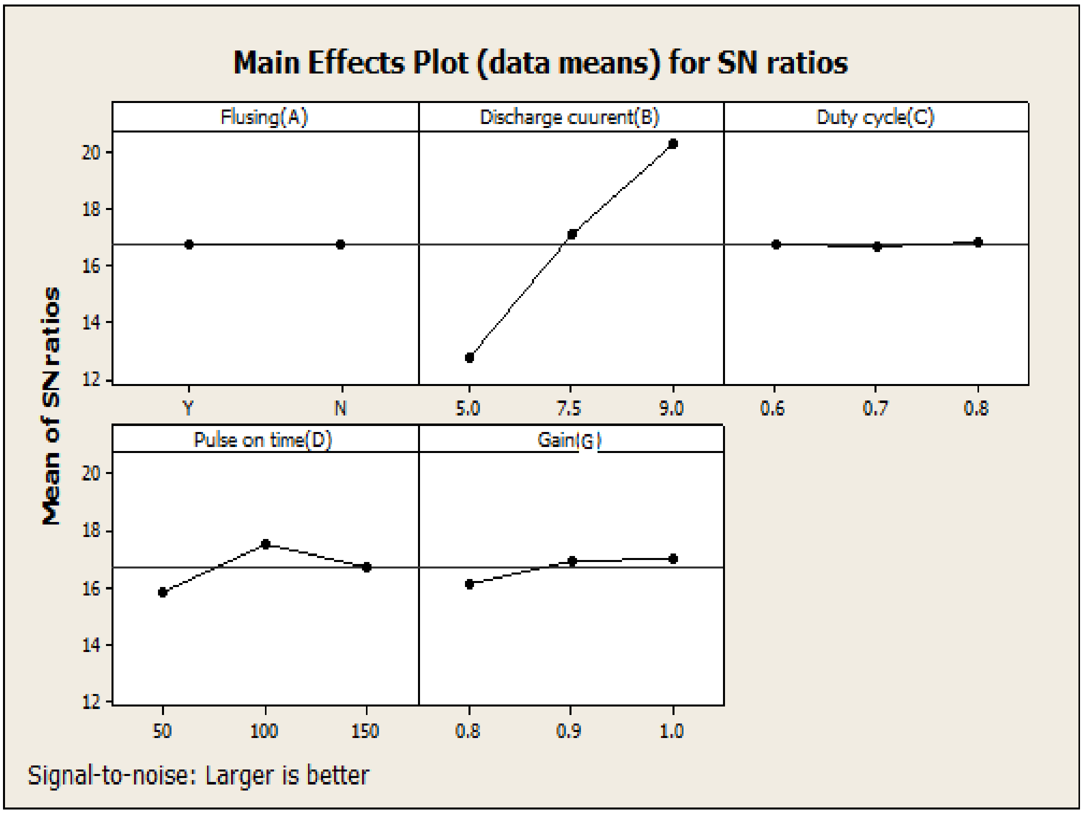

Fig- 4 Main Effects Plot (data means) for S/N ratios for traditional EDM

The effects of the five parameters on the average value of MRR and S/N ratios are shown in Table 7**.** The mean value and S/N ratio of MRR for each run are calculated from experimental data . The effect of parameters on the mean values of S/N ratios of each level of control variables are as shown in fig 4. From Table 7 these figs clearly indicates that the factor, discharge current is the most influencing parameter, followed by pulse on time, with increase in pulse on time MRR increases first and then decreases. This shows that very short pulse duration causes less vaporization. The optimum parametric combination for traditional EDM is A1B3C3D2E3.

Table 9 - Confirmation Experiment for MRR

Traditional EDM			**Abrasive mixed EDM**		
Expected optimum Combination	Expt.value	Avg.value	Expected optimum combination	Expt.value	Avg.value
A1B3C3 D2E3	7.95 mm3/min	7.84 mm3/min	A1B3C2D2 E2F3G3	13.65 mm3/min	12.47 mm3/min

6. COMPARISON OF TRADITIONAL EDM WITH ABRASIVE MIXED EDM.

Traditional EDM is compared with abrasive mixed EDM, in respect of MRR on the basis of confirmation test. The experiments were carried out using the same parameter level setting factors of abrasive particle size and abrasive particle concentration in traditional EDM. Based on the fig.4 it can be observed that the material removal rate is poor in traditional EDM than the abrasive mixed EDM. In this study the MRR obtained in abrasive mixed EDM is 58% more than the traditional EDM.

It is observed that MRR increases with the addition of the abrasive particles with a proper particle size. The reason for the enhancement of MRR is mainly attributed to the lower breakdown strength of the dielectric fluid when abrasive particles are added to it. The optimum combinations are shown in table 9.

CONCLUSIONS

The present investigation has been carried out to assess the effect of process parameters on the MRR of D3 Die steel for both traditional EDM and abrasive mixed EDM. The experiments were carried out by design of experiments using number of variables at different levels. Taguchi technique is used for design and optimization of the process parameters with the use of Minitab software in both the machining processes. The ANOVA was used to evaluate the statistical significance of each factor on the performance characteristics. Based on the results of theoretical analysis the fallowing conclusions are made.

1). By adding the abrasive particles into the dielectric fluid, efficiency of the machining is improved due to discharging energy dispersion.
2). Abrasive particles make discharge break down easier, enlarges the discharge gap.
3). As per S/N ratio and ANOVA, MRR is influenced by discharge current and abrasive concentration.
4). MRR increases with increase in the concentration of the Al2O3 abrasive, at 6g/lit of concentration in the dielectric fluid, MRR is maximum.
5). The MRR decreases with increase of abrasive particles concentration after certain limit.
6). In this study the abrasive mixed EDM results in 58% more MRR than the traditional EDM.

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