Parametric Optimization of Electric Discharge Drilling Machine Using Al-SiC Metal Matrix Composite

S.Vijaya Kumar
AP/Mechanical Engineering, Muthayammal Engineering College, Rasipuram, Namakkal, Tamilnadu, India
Email: vijaisuriyaa2010@gmail.com +91-9629723720

C.Srinivasan
AP/Mechanical Engineering, Muthayammal Engineering College, Rasipuram, Namakkal, Tamilnadu, India
Email: srinime89@gmail.com +91-9047710365

P.Paramasivam
AP/Mechanical Engineering, Muthayammal Engineering College, Rasipuram, Namakkal, Tamilnadu, India
Email: paramasivamani@gmail.com +91-7708432392

M.Maniyarasan
AP/Mechanical Engineering, Muthayammal Engineering College, Rasipuram, Namakkal, Tamilnadu, India
Email: arasan6065@gmail.com +91-8508509789

Abstract - Electric Discharge Drill Machine (EDDM) is a spark erosion process to produce micro and small holes in conductive materials. This process is widely used in aerospace, medical, dental and automobile industries.

As for the performance evaluation of the Electric discharge drilling machine it is very necessary to study the process parameters of machine tool. In this study a brass rod of 1 mm diameter was selected as a tool electrode.

The experiments generate output responses such as material removal rate (MRR) and tool wear rate (TWR). The parameters such as pulse on-time, Pulse off-time and water pressure were studied for best machining characteristics. This investigation presents the use of Taguchi approach for better MRR in drilling of Al-6061 based composites. The experiments were performed based on L27 orthogonal array as per Taguchi's design of experiment concept.

From the analysis of variance the percentage contribution of the control factor in the machining of Al-6061 based composites in EDDM were obtained.

The optimal combination levels and the significant drilling parameters on MRR and TWR were obtained. The optimization results showed that the combination of maximum pulse on-time and minimum pulse off-time gives maximum MRR and minimum pulse on-time and maximum pulse off-time gives minimum TWR.

Index Terms- EDDM, MMC-Metal Matrix Composite, MRR Stir casting, SiC, TWR.

I. INTRODUCTION

Samar Singh et.al [1] study in this research paper a brass rod 2 mm diameter was selected as a tool electrode. The experiments generate output responses such as material removal rate (MRR). The best parameters such as pulse on-time, Pulse off-time and water pressure were studied for best machining characteristics. A plan of experiments, based on L27 Taguchi design method

A.TolgaBozdana et.al [2] reports an experimental investigation of EDM drilling of 2 mm diameter holes on Inconel 718 using brass electrode. The effect of process parameters (discharge current, pulse on and off times, and capacitance) on process outputs (material removal rate and electrode wear rate) was determined based on minimum number of experiments. The mathematical modelling of process has been done using Response Surface Methodology.

Ruben Phipon et.al [3] this present research study deals with the single and multi objective optimization of micro EDM process using Genetic Algorithm. Mathematical models using Response Surface Methodology (RSM) is used to correlate the response and the parameters.

C. Diver et.al [4] this papers details the development of a novel technique to produce reverse tapered micro-holes the quality of the holes produced is examined using a novel 3D impression technique, as well as SEM, surface roughness, and 3D optical measurements.

O. Yilmaz, et.al [5] a comparative investigation of fast hole drilling of aerospace alloys, namely as Inconel 718 and Ti-6Al-4V using electrical discharge machining (EDM) method was performed in order to explore the influence of electrode type and material. The experimental results reveal that the single-channel electrodes have comparatively better MRR and lower Electrode wear.

Electric Discharge Drill Machine (EDDM) is a spark erosion process to produce micro and small holes in conductive materials. As for the performance evaluation of the Electric discharge drilling machine it is very necessary to study the process parameters of machine tool.

In this experiment the optimization based on brass tube of diameter 1 mm taken as a electrode and Al-SiC metal matrix composites taken as a work piece from these two kind of materials MRR and TWR is analyzed by L27 Taguchi design method.

ISSN: 2278 – 7798

II. EXPERIMENTAL PROCEDURE

A. SPECIMEN PREPARATION

The specimen is must be prepared by considering various process parameters like and all the steps for the preparation of Al-SiC composites are followed. The steps include weight calculation, fabrication (casting and machining) and experiment conduct.

TABLE 1
PROPERTIES OF Al 6061 AND SiC

Properties	Al 6061	SiC
Elastic Modulus (GPa)	70-80	410
Density (g/cc)	2.7	3.1
Poisson's Ratio	0.33	0.14
Hardness (kg/mm^2)	95	2800
Modulus of rigidity (GPa)	26	140
Shear strength (MPa)	83	-
Tensile Strength (MPa)	115	390

FORMULAE:

Weight = Volume x Percentage x Density

Density of Al alloy=2.72g/cm^3

Density of SiC alloy=3.21g/cm^3

TABLE 2
WEIGHT OF Al alloy and SiC

S.No	Samples	Weight of Al Ingot in Grams	Weight of SiC powder in Grams
1	For 6% of SiC	306.8	23.1

B. EXPERIMENTAL SETUP

Fig. 1 and Fig. 2 show the preheating furnace and stir casting furnace. Stir casting method is used to melt the Aluminium ingots. The coil transfers the heat to the crucible and melts the metal.

Fig.1 Pre Heating Furnace

Fig.2 Stir Casting Furnace

The melting capacity of the stir casting furnace is 3 kg. SiC preheated in preheating chamber around 850^{0}C.Required Quantity of Al metal is charged into the main crucible and placed inside the furnace and heated by coil.

A stirrer positioned at the top of the furnace is used to mixing the reinforcement in the molten metal. An electric motor is used to rotate the stirrer through belt drive, at 1200 rpm. As Stirrer has to rotate at 600 rpm, the shaft and the stirrer have large pulley which reduce the rpm. Die is made of wood which has one part of 20x20 mm in cross section and 300mm length.

C. FABRICATION

Aluminium particle is charged into the crucible and kept inside the furnace and covered. Switch on the furnace and temperature is gradually raised up to 900°C.

Pre heated reinforcement (around 850°C) is adding into molten metal in main furnace crucible and Stirrer with 5minutes.

From the stirring action of 5 minutes the reinforced material is evenly distributed entire liquid metal.

Clean the die before pouring the liquid metal, so that it reduces the solidification rate. Magnesium is added to the liquid metal which increases the wet ability of the matrix and assisted particle incorporation.

The liquid stage metal matrix composite is taken out and poured in to the die then cooled. Cast specimen shown in Figure 3.

Fig. 3 Cast specimen

ISSN: 2278 – 7798

D. MACHINING

After casting the work piece is machined by ordinary lathe in required dimensions of 10mmx10mmx150mm.

E. PROBLEM IDENTIFICATION

Stirrer blade starts to erode at 600 rpm at high temperature.Tool (High Speed Steel) was getting blunted while machining the specimen.

III. INVESTIGATION OF MRR & TWR

Experiments are performed on Electronica Make ED 300 Electric discharge drilling Machine as shown in fig. 4. The goal is to obtain the best machining parameters resulting in Maximum MRR and minimum TWR. Holes were made in a 10 mmX10 mm cross section square piece of Al 6061 based composites using a 1 mm diameter electrode of Brass in 27 pitches. Take job centre in y-axis and edge reference in x-axis. Here pitch means y axis is constant and x axis varies from 5, 10… 135mm.

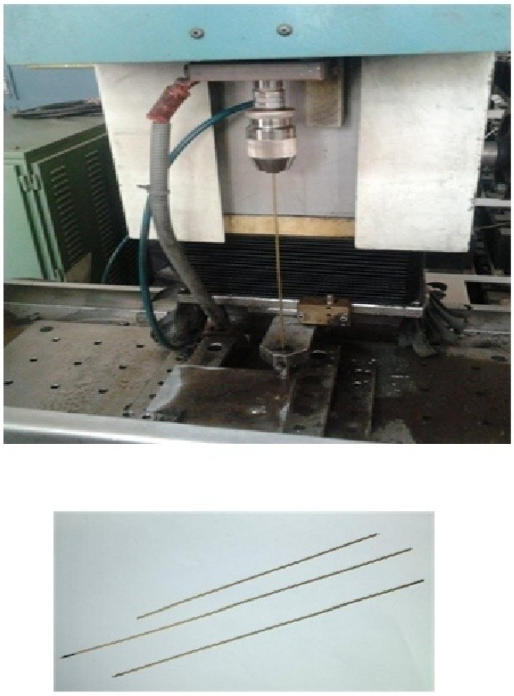

Fig. 4 Experimental set up of EDM drilling machine

The initial weight of the work piece was precise weighed using an accuracy digital scale. The work piece was connected to the terminals of power supply and clamped on the machine table. The dielectric fluid was flushed at a Constant pressure in the gap between electrode and work piece. Holes of 10 mm depth were drilled in all the experiments. The time taken for machining each hole was recorded. At completion of each hole the Work piece was removed from the machine, washed, dried, and weighted. The material removed rate and tool wear rate was calculated using the following formula (1) and (2)

$$\text{MRR} = \frac{\text{(Weight of the Work piece before machining - Weight of the Work piece after machining)}}{\text{Machining time}} \text{ mg/s} \quad (1)$$

$$\text{TWR} = \frac{\text{(Weight of the Electrode before machining - Weight of the Electrode after machining)}}{\text{Machining time}} \text{ mg/s} \quad (2)$$

An L27 orthogonal array has been employed as per Taguchi's method based robust design philosophy to evaluate the main influencing factors that affect the material removal rate (MRR) and tool wear rate (TWR).three EDDM parameters pulse on-time, pulse off-time and water pressure are considered as the controlling factors for optimal analysis during drilling of material.

IV.DESIGN OF EXPERIMENTS

After you have identified the "vital few" by screening, you need to determine the "best" or optimal values for these experimental factors. Optimal factor values depend on the process objective. For example, you may want to maximize process yield or reduce product variability. The optimization methods available in Minitab include general full factorial designs (designs with more than two-levels), response surface designs, mixture designs, and Taguchi designs.

A.TAGUCHI DESIGN EXPERIMENTS IN MINITAB 14

Before you begin using Minitab, you need to complete all pre-experimental planning. For example, you need to choose control factors for the inner array and noise factors for the outer array. Control factors are factors you can control to optimize the process. Noise factors are factors that can influence the performance of a system Use Create Taguchi Design to generate a Taguchi design (orthogonal array). Or, use Define Custom Taguchi Design to create a design from data that you already have in the worksheet. Define Custom Taguchi Design allows you to specify which columns are your factors and signal factors. You can then easily analyze the design and generate plots.

After you create the design, you may use Modify Design to rename the factors, change the factor levels, add a signal factor to a static design, ignore an existing signal factor (treat the design as static), and add new levels to an existing signal factor. Perform the experiment and collect the response data. Then, enter the data in your Minitab worksheet. See Collecting and Entering Data. Use Analyze

ISSN: 2278 – 7798

Taguchi Design to analyze the experimental data. See Analyzing Taguchi Designs. Use Predict Results to predict S/N ratios and response characteristics for selected new factor settings. See Predicting Results.

B. SINGLE-LEVEL DESIGNS

The table below summarizes the single-level Taguchi designs available. The number following the "L" indicates the number of runs in the design. In this investigation L27 Taguchi design is used with has 27 runs. The numbers in the table indicate the minimum and maximum number of available factors for each design.

TABLE 3
SINGLE-LEVEL TAGUCHI DESIGNS

	Number of levels			
Designs	2	3	4	5
L4 (2**3)	2-3			
L8 (2**7)	2-7			
L9 (3**4)		2-4		
L12 (2**11)	2-11			
L16 (2**15)	2-15			
L16 (4**5)			2-5	
L25 (5**6)	2-6			
L27 (3**13)		2-13		
L32 (2**31)	2-31			

V. RESULTS AND DISCUSSION

A. EXPERIMENTAL VALUES OF MRR AND TWR

From the experiment ,MRR and TWR are calculated and summaries as follows in the table 5.1,5.2 and 5.3 these tables represent the MRR and TWR for the various pulse on-time, pulse off-time and water pressure

The different sets of experiments are performed on EDDM. The work material, electrode and other machining conditions are as follows:

- Electrode: brass
- Work piece: Al-SiC composite
- On time :(25-75) µs
- Off time:(10-20) µs
- Water pressure:(25-35) Kg/cm^2

Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio (S/N).These S/N ratios are derived from the quadratic loss function and among the three, the following is "Smaller the best" is considered to be standard and widely applicable: Where y is the average of observed data, n is the number of observations.

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

The optimal setting is the parameter combination that has highest S/N ratio. The statistical analysis of the data is performed by analysis of variance (ANOVA) to study the contribution of the factor and interactions and to explore the effects of each process on the observed value.

TABLE 4
EXPERIMENTAL VALUES

S.NO	ON TIME (µs)	OFF TIME (µs)	FLUSHING PRESSURE (Kg/cm^2)	MRR gm/min	TWR gm/min
1	25	10	25	0.032	0.07
2	25	10	30	0.034	0.068
3	25	10	35	0.036	0.067
4	25	15	25	0.025	0.064
5	25	15	30	0.022	0.062
6	25	15	35	0.026	0.061
7	25	20	25	0.021	0.06
8	25	20	30	0.023	0.059
9	25	20	35	0.024	0.057
10	50	10	25	0.04	0.08
11	50	10	30	0.043	0.078
12	50	10	35	0.044	0.077
13	50	15	25	0.042	0.076
14	50	15	30	0.044	0.074
15	50	15	35	0.045	0.073
16	50	20	25	0.041	0.07
17	50	20	30	0.042	0.069
18	50	20	35	0.044	0.067
19	75	10	25	0.054	0.092
20	75	10	30	0.055	0.09
21	75	10	35	0.058	0.089
22	75	15	25	0.05	0.088
23	75	15	30	0.052	0.086
24	75	15	35	0.053	0.085
25	75	20	25	0.05	0.084
26	75	20	30	0.052	0.082

ISSN: 2278 – 7798

27	75	20	35	0.053	0.08

TABLE 5
EXPERIMENTAL VALUES and S/N ratios for MRR

S.No	On Time (µs)	Off Time (µs)	Flushing Pressure (Kg/cm²)	MRR gm/min	TWR gm/min	SNR1	Mean1
1	25	10	25	0.032	0.07	-29.897	0.032
2	25	10	30	0.034	0.068	-29.3704	0.034
3	25	10	35	0.036	0.067	-28.8739	0.036
4	25	15	25	0.025	0.064	-32.0412	0.025
5	25	15	30	0.022	0.062	-33.1515	0.022
6	25	15	35	0.026	0.061	-31.7005	0.026
7	25	20	25	0.021	0.06	-33.5556	0.021
8	25	20	30	0.023	0.059	-32.7654	0.023
9 TWR	**25**	**20**	**35**	**0.024**	**0.057**	**-32.3958**	**0.024**
10	50	10	25	0.04	0.08	-27.9588	0.04
11	50	10	30	0.043	0.078	-27.3306	0.043
12	50	10	35	0.044	0.077	-27.1309	0.044
13	50	15	25	0.042	0.076	-27.535	0.042
14	50	15	30	0.044	0.074	-27.1309	0.044
15	50	15	35	0.045	0.073	-26.9357	0.045
16	50	20	25	0.041	0.07	-27.7443	0.041
17	50	20	30	0.042	0.069	-27.535	0.042
18	50	20	35	0.044	0.067	-27.1309	0.044
19	75	10	25	0.054	0.092	-25.3521	0.054
20	75	10	30	0.055	0.09	-25.1927	0.055
21 MRR	**75**	**10**	**35**	**0.058**	**0.089**	**-24.7314**	**0.058**
22	75	15	25	0.05	0.088	-26.0206	0.05
23	75	15	30	0.052	0.086	-25.6799	0.052
24	75	15	35	0.053	0.085	-25.5145	0.053
25	75	20	25	0.05	0.084	-26.0206	0.05
26	75	20	30	0.052	0.082	-25.6799	0.052
27	75	20	35	0.053	0.08	-25.5145	0.053

MODEL CALCULATION FOR S/N RATIO IN MRR

S/N=-10 log $(1/0.032^2)$ (larger the better)

=-29.897

TABLE 6
EXPERIMENTAL VALUES and S/N ratios for TWR

S.No	On Time (µs)	Off Time (µs)	Flushing pressure (Kg/Cm²)	MRR gm/min	TWR gm/min	SNR2	Mean2
1	25	10	25	0.032	0.07	23.098	0.07
2	25	10	30	0.034	0.068	23.3498	0.068
3	25	10	35	0.036	0.067	23.4785	0.067
4	25	15	25	0.025	0.064	23.8764	0.064
5	25	15	30	0.022	0.062	24.1522	0.062
6	25	15	35	0.026	0.061	24.2934	0.061
7	25	20	25	0.021	0.06	24.437	0.06
8	25	20	30	0.023	0.059	24.583	0.059
9TWR	**25**	**20**	**35**	**0.024**	**0.057**	**24.8825**	**0.057**
10	50	10	25	0.04	0.08	21.9382	0.08
11	50	10	30	0.043	0.078	22.1581	0.078
12	50	10	35	0.044	0.077	22.2702	0.077
13	50	15	25	0.042	0.076	22.3837	0.076
14	50	15	30	0.044	0.074	22.6154	0.074
15	50	15	35	0.045	0.073	22.7335	0.073
16	50	20	25	0.041	0.07	23.098	0.07
17	50	20	30	0.042	0.069	23.223	0.069
18	50	20	35	0.044	0.067	23.4785	0.067
19	75	10	25	0.054	0.092	20.7242	0.092
20	75	10	30	0.055	0.09	20.9151	0.09
21 MRR	**75**	**10**	**35**	**0.058**	**0.089**	**21.0122**	**0.089**
22	75	15	25	0.05	0.088	21.1103	0.088
23	75	15	30	0.052	0.086	21.31	0.086
24	75	15	35	0.053	0.085	21.4116	0.085
25	75	20	25	0.05	0.084	21.5144	0.084
26	75	20	30	0.052	0.082	21.7237	0.082
27	75	20	35	0.053	0.08	21.9382	0.08

MODEL CALCULATION FOR S/N RATIO IN TWR

ISSN: 2278 – 7798

$S/N = -10 \log (0.07^2)$ (Smaller the better)

$= 23.098$

TABLE 7
ANALYSIS OF VARIANCE FOR MRR, USING ADJUSTED SS FOR TESTS

Source	DF	Seq SS	Adj SS	Adj MS	F	P
On time	2	0.0001 022	0.0001 042	0.0000 521	217.14	0.000
Off time	2	0.0000 041	0.0000 041	0.0000 020	8.44	0.002
Flushing pressure	2	0.0000 019	0.0000 019	0.0000 010	3.98	0.035
Error	20	0.0000 048	0.0000 048	0.0000 002		
Total	26	0.0001 130				

S = 0.000489831 R-Sq = 95.75%
R-Sq (adj) =94.48%

TABLE 8
ANALYSIS OF VARIANCE FOR TWR, USING ADJUSTED SS FOR TESTS

Source	DF	Seq SS	Adj SS	Adj MS	F	P
On time	2	0.0001 765	0.0001 779	0.0000 889	3361.6 5	0.000
Off time	2	0.0000 279	0.0000 280	0.0000 140	528.32	0.002
Flushing pressure	2	0.0000 033	0.0000 033	0.0000 016	62.36	0.000
Error	20	0.0000 005	0.0000 005	0.0000 016		
Total	26	0.0002 082				

S = 0.000162652 R-Sq = 99.75%
R-Sq (adj) = 99.67%

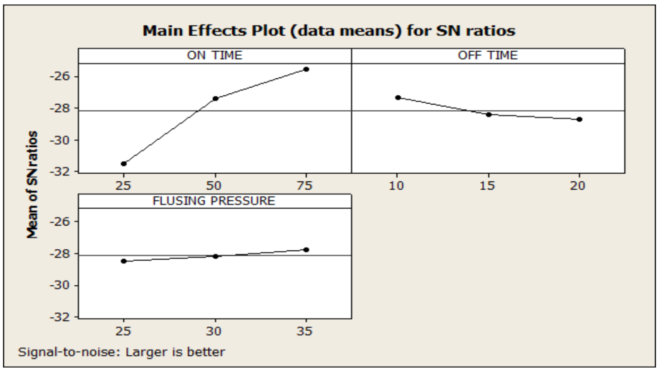

FIG.5 GRAPH MRR VS ON TIME, OFF TIME AND WATER PRESSURE

B. OPTIMUM CONDITION FOR MRR

On Time =75 µS
Off Time=10 µS
Flushing Pressure=35 Kg/cm^2

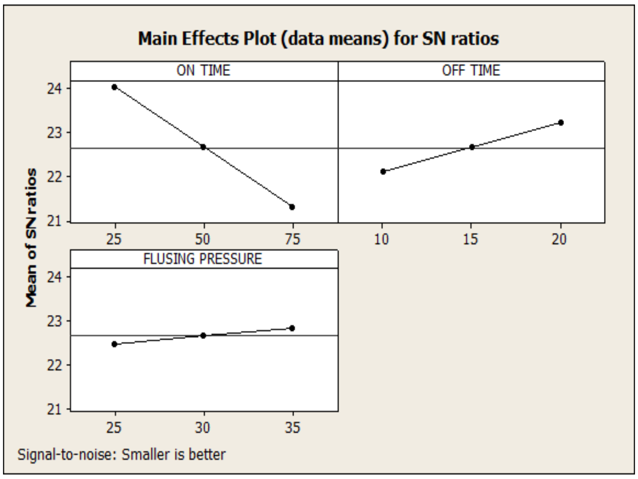

FIG.6 GRAPH TWR VS ON TIME, OFF TIME AND WATER PRESSURE

C. OPTIMUM CONDITION FOR TWR

On Time =25 µS
Off Time=20 µS
Flushing Pressure=35 Kg/cm^2

VI. CONCLUSION

The effects of various drilling parameters on the tool wear rate and material removal rate of Al-SiC plate were investigated. The following conclusion can be drawn on the basis of the present experimental investigation:

From the mathematical modeling, the regression co-efficient (R2) value for tool wear rate (TWR) is 99.6% and for material removal rate (MRR) is 94%. This enables the good prediction accuracy. The regression co-efficient (R2) value is the measure of the goodness of fit of the model, 99.6% of the total variation was explained by the model for TWR and 94% for MRR.

ISSN: 2278 – 7798

From ANOVA results, pulse on time has the maximum (90.4%) influence on the material removal rate followed by pulse off time (3.6%) and flushing pressure of (1.7%) influence the MRR.

From ANOVA results, pulse on time has the maximum (84.7%) influence on the tool wear rate followed by pulse off time (13.4%) and flushing pressure of (1.5%) influence the TWR.

VII. REFERENCES

1. Samar Singh, MukeshVerma , A Parametric Optimization of Electric Discharge Drill Machine Using Taguchi Approach, Journal of Engineering, Computers & Applied Sciences (JEC&AS)ISSN No: 2319-5606 Volume 1, No.3, December 2012
2. A. Tolga Bozdana1, Oguzhan Yilmaz, Mathematical modeling of EDM hole drilling using response surface methodology, Technological Research Council of Turkey (TUBITAK) Scientific and Technological Project Scheme, Grant No. 108M022.
3. Ruben Phipon* and B.B.Pradhan , Process Parameters Optimization Of Micro Electric Discharge Machining Process Using Genetic Algorithm, International Journal of Engineering Research and Applications Vol. 2, Issue 5, September- October 2012, pp.1986-1993
4. C. Divera,, J. Atkinsonb, Micro-EDM drilling of tapered holes for industrial applications, Journal of Materials Processing Technology 149 (2004) 296-303
5. O.Yilmaz, A.T. Bozdana, A comparative investigation of the effects of single and multi-channel electrodes in EDM fast hole drilling of aerospace alloys , The Scientific and Technological Research Council of Turkey (TUBİTAK)Scientific and Technological Project Scheme, Grant No. 108M022
6. Pichai Janmaneea, and Apiwat Muttamaraa, A Study of Hole Drilling on Stainless Steel AISI 431 by EDM Using Brass Tube Electrode , 2011 International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies
7. Ramezan Ali MahdaviNejad , Modeling and Optimization of Electrical Discharge Machining of SiC Parameters, Using Neural Network and Non-dominating Sorting Genetic Algorithm (NSGA II) , Materials Sciences and Applications, 2011, 2, 669-675
8. Qing GAO†, Qin-he ZHANG, Parameter optimization model in electrical discharge machining process, Journal of Zhejiang University SCIENCE
9. Miss.Swati.D.Lahane1, Prof.Manik.K.Rodge2, Multi-response optimization of Wire-EDM process using principal component analysis, IOSR Journal of Engineering (IOSRJEN) ISSN: 2250-3021 Volume 2, Issue 8 (August 2012), PP 38-47
10. Manish Vishwakarma, 2v.K.Khare, Response surface approach for optimization of Sinker Electric Discharge Machine process parameters on AISI 4140 alloy steel, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622

ISSN: 2278 – 7798