DEVELOPMENT OF REGRESSION MODEL FOR Al6061+ SiC TOOL AND OPTIMIZATION OF PROCESS PARAMETERS ON ELECTRO DISCHARGE MACHINING

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Abstract—Proper 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). These are the conditions that determine important characteristics such as material removal rate , Electrode Wear. In the present work experiments are conducted on EDM using Al6061+SiC (with 3%,6%,9% composition of SiC in Al 6061 Alloy),Copper and Brass materials as electrodes and EN8 steel as work material. Discharge current (I_P), pulse on time (T_{ON}), pulse off time (T_{OFF}) are selected as inout process parameters , Metal Removal Rate (M_R), Tool Wear Rate (TWR) as response. Taguchi design of experiment is used to find the influence of process parameters on response and a mathematical model is developed. Percentage contribution of each factor is determined.

Keywords— Discharge current(I_P), Pulse on time (T_{ON}), Pulse off time (T_{OFF}), Voltage (V), Metal Removal Rate,EDM

1. INTRODUCTION

Electrical Discharge Machining (EDM) process involves a controlled erosion of electrically conductive materials by initiation of rapid and repetitive spark discharge between electrode tool and work piece, separated by a small gap of about 0.01 to 0.05mm known a spark gap. This is either flooded or immersed under dielectric fluid. The controlled pulsing of direct current produces the spark discharge between the work piece and tool. Each spark produces enough heat to melt and vaporize a tiny volume of the work piece material leaving a small crater on its surface. The energy contained in each spark is discrete and it can be controlled so that material removal rate, surface finish and tolerance can be produced. EDM is most widely used machining process among the non-traditional machining methods. It is successfully employed for producing intricate and irregular shape profiles common in tool rooms.

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NOMENCLATURE

EDM	Electrical Discharge Machining
MRR	Metal Removal Rate
I_P	Discharge Current
T_{ON}	Pulse on Time
T_{OFF}	Pulse of Time
V	Voltage
µs	Micro second
A	Ampere
DoE	Design of Experiments

2. LITERATURE REVIEW

The Following Literature Review is observed in the investigation on EDM.

- Sushil Kumar Choudharyetal.[[1]in their study on "Current Advanced Research Development of Electric Discharge Machining (EDM): A Review" carried out the work on shaping hard metals and forming deep complex shaped holes by arc erosion in all kinds of electroconductivematerials.
- K.H. Ho, S.T. Newman [2],in their study on "State of the art electrical discharge machining (EDM)",discuss about the die making process to a micro-scale application machining.
- Rao, P. Srinivasa et al.[3] have studied that have an effect on by means of design four factors such as current, servo control, duty cycle and open circuit voltage over the outputs on the MRR, TWR, SR and hardness on the die-sinker EDM process of machining AISI 304 SS.
- S. H. Tomadiet al.[4] analyzed that impact of machining settings of the tungsten carbide on the outputs such as TWR, MRR and Surface finish. To find errors between the predicted values and to experimental runs in terms of machining characteristics. They were found out copper tungsten tool use for better surface finishing of work piece. They were using full factorial DoE, to optimization and discovered out with greater pulse off time lesser tool wear of the tungsten carbide and with current, voltage and pulse on time increment with tool wear increased.
- Zhao Wanshenget al.[5] have studied about surface machining process by EDM. Shows the consists of a series of discharge craters, and explain that there is no screw-like trail left on the hole's inside wall that would be formed by ordinary drilling. This can change the field of distribution condition when fluid or gas flows through the small hole. As there is no macroscopic force, it is easy to machine a half hole by using EDM.
- UlasÇaydaset al.[6] analyzed that the EW and WLT in die-sinking EDM process were modeled and analyzed through response surface methodology (RSM). A valuable central composite rotatable design (CCRD) in RSM consisting of three variables. Pulse on time, pulse off-time and pulse current have been employed to carry out the experimental study have a look at. Analysis of variance (ANOVA) was applied to study. Their predicted values match the experimental values reasonably nicely, with R2 of 0.99 for EW and R2 of 0.97 for WLT.
- H. Shen et al. [7] have studied in micro EDM, they defined about the discharge gap that is very small, and the dimensions of the electrode is just too small to use internal and/or outside flushing to dispose of debris. In their paper, a new method the usage of planetary movement of the electrode is proposed to lessen the particles concentration and enhance precision. The planetary movement of electrode provides extra area for particles elimination. Therefore, the material removal rate increases and the electrode wear reduce. This method has been confirmed through machining of micro holes with excessive element ratio and blind noncircular micro holes.
- G. Appa Rao et al. [8] have studied the effect of normal heat treatment on the microstructure and mechanical properties of hot isostatically pressed superalloyinconel 718. In this, Inconel 718 was analyzed processed through powder metallurgy (P/M) hot isostatic pressing (HIP) route. In this study, they have led to better study of the property and structure relationships in HIP + heat treated analysis on alloy 718 and suggest that the standard heat treatment approved for wrought IN 718 is not convenient for HIPed alloy and has to be modified to realize optimum properties.
- Mr.V.D.Patel, Prof.C.P.Patel, Mr.U.J.Patel [10] their study on "Analysis of different tool material on MRR and surface roughness of Mild Steel In EDM" (Sep-Oct 2011), have conducted experimental work on Mild steel with copper, Brass and graphite as tool electrodes with kerosene oil as dielectric fluid and have studied the pattern of HAZ's for different tool material.

- The stress rupture life and ductility of the alloy have also made better marginally after heat treatment and has got the minimum expected life for wrought heat treated IN 718, however, the rupture ductility was found to be much less than the specified value. This suggest that the recommended heat treatment for wrought alloy is not suitable for HIP processed alloy and has to be modified to realize optimum properties.
- Kuldeep Ojha, R.KGarg,K.K.Singh(2010) [19] in their study on " MRR improvement in Sinking Electrical Discharge Machining" have researched on the development resulting in improvement in material removal rate.
- Arun Kumar M.B and R.P.Swamy [20] in their study on “Evaluation of mechanical properties of Al6061, Flyash and E-Glass fiber reinforced Hybrid metal matrix”(May-2011) It has been observed that the addition of flyash significantly improves ultimate tensile strength along with compressive strength and hardness properties as compared to that of reinforced matrix.
- AshwaniKharola [21] in “ Analysis of Various machining parameters of EDM on Hard Steel using copper and Aluminium electrodes” (March 2015) have studied the process parameters on EDM using Copper, Aluminium electrodes and EN8 work material.”
- J. Laxman and Dr.K.Gururaj [22] in their journal “Modeling and Analysis of EDM process parameters using Taguchi technique and Fuzzy based modeling” (2014) Experiment were designed by Taguchi’s technique and conducted by taking three levels of the peak current, pulse on time, pulse off time and tool life time on Titanium super alloy.
- J.Jeevamalar and S. Ramabalan [23] in their article “Die sinking process parameters” have given a detailed explanation of Die sinker EDM, MRR, TWR, SR,Taguchi method.
- C. Mathalai Sundaram, R.Sivasubramanian, M.Sivakumar [24] in their study on “ An Experimental Investigation on Machining Parameters of Electrical Discharge Machining of OHNS Steel” have studied the EDM process performance and the machining conditions with Copper and Aluminium tool electrode and its effects on the process output parameters viz, material removal rate and tool wear rate and percentage wear rate.
- VedPrakashPandey, MrR.N.Mall [25] in their study on “Analyis of material removal rate of AlSi 304 SS in EDM process” have studied the effect of various process parameters.
- MehulG.Mehta, Nikul.K.Patel [26] in their study on “Temperature and thermal stress analysis of EDM” (Jan-2014), have presented a basic review on the different parameters and the various methods applied to estimate the temperature distribution and thermal stress analysis.
- BholaJha, K.Ram and Mohan Rao [27] in their study on “An overview of technology and research in electrode design and manufacturing in sinking electrical discharge machining” (Dec-2011), have reported a review on the research related to EDM electrode deign and its manufacturing for improving and optimizing performances.

3. OBJECTIVES & METHODOLOGY

The objecvtive of the current work is to develop Mathematical model for the input and out parameters considered . Design of experiments is adopted in order to run minimum number of experimental trials. Experiments are carried out as per the design matrix. Adequacy of model is tested by fisher test at 5% significance level. Student’s t-test is done for each regression coefficient to check the significance. The final mathematical model is formed by removing non significant coefficients. Analysis of Variance (ANOVA) is done to find out the percentage contribution of each factor to the Metal Removal Rate and Tool Wear Rate.

Design Of Experiments - Taguchi Method

Taguchi has envisaged a new method of conducting the design of experiments which are based on well defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting minimal number of experiments which could give the full information of all the factors that affects the performanceparameters. There are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels. The L9 orthogonal array is meant for understanding the effect of 4 independent factors each having 3 factor level values. This array assumes that there is no interaction between any two factors. While in many cases, no interaction model assumption is

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valid, there are some cases where there is clear evidence of interaction. A typical case of interaction would be the interaction between the material properties and temperature.

Postulation of Mathematical Model

The regression equation is an algebraic representation of the regression line and describes the relationship between the response and predictor variables. The regression equation takes the form of:

Response = constant + coefficient * predictor + ... + coefficient * predictor

or $y = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k$

Where:

- Response (Y) is the value of the response.
- Constant (b_o) is the value of the response variable when the predictor variable(s) is zero. The constant is also called the intercept because it determines where the regression line intercepts (meets) the Y-axis.
- Predictor(s) (X) is the value of the predictor variable(s). The predictor can be a polynomial term.
- Coefficients (b_1, b_2, ... ,b_k) represent the estimated change in mean response for each unit change in the predictor value. In other words, it is the change in Y that occurs when X increases by one unit.

Table 1: EDM Factors and Levels

Process parameter	Units	Level 1	Level 2	Level 3
Pulse on time(T_{ON})	µs	200	500	900
Pulse off time(T_{OFF})	A	100	200	500
Voltage(V)	V	30	40	45
Current(I)	µs	6	8	10

The EDM process variables (factors) are identified to develop the mathematical model to predict the MRR and Tool Wear . These include pulse on time (T_{ON}), pulse off time (T_{OFF}) and pulse current (Ip), Voltage (V) . The first order model is assumed with two and three four interactions which can be expressed as

4. EDM PROCESS CHARACTERISTICS

Metal removal rate is calculated from weight difference of work piece before and after the performance trail.

$$MRR = (w_1\text{-}w_2)/(\text{Machining time})$$

Where,
w_1= initial weight of the workpiece before machining
w_2= final weight of the workpiece after machining
Machining time= 10 minutes

To convert MRR into g/hour multiply with 6000 with MRR (kg/min)

$$MRR(g/hour) = MRR(kg/min) * 600$$

Tool Wear Rate is calculated from weight difference of Tool before and after the experimentation. Tool Wear Rate is given by

$$TWR = (M_1\text{-}M_2)/(\text{Machining time})$$

Where,
M_1= initial weight of the Tool before machining
M_2= final weight of the Tool after machining
Machining time= 90 minutes

5. Experimentation (Machining of EN8 on EDM With Al6061+SiC (3%,6%,9%), Copper and Brass tools)

The experimentation is carried out on SYCNC PC-60 Electrical Discharge Machine as per L9 orthogonal array (Table 2).The polarization on the electrode be located as negative whereas that of work piece be located as positive. The dielectric liquid recycled was EDM oil having specific gravity 0.763. Fig -1 shows the Experimental setup, Fig-2 shows the Various Tools, Fig-3 shows Machined components.

Fig. 1. Experimental setup

Fig 2. Tools used for Experimentation

Fig 3:Experimentation on EN8 with Al6061+SiC(3%,6%,9%),Copper and Brass tools

Experiment with Al6061+3%SiC

Experiment with Al6061+6%SiC

Experiment with Al6061+9%SiC

Experiment with Copper

Experiment with Brass

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Table 2. MRR for Al6061+SiC(3%,6%,9%), Copper & Brass Electrodes

S. NO	PULSE ON TIME (µs)	CURRENT (A)	VOLTAGE (V)	PULSE OFF TIME (µs)	METAL REMOVAL RATE (g/hour)				
					Al6061 +3%SiC	Al6061 +6%SiC	Al6061 +9%SiC	COPPER	BRASS
1	200	6	30	100	0.84	0.84	2.16	3	0.9
2	200	8	40	200	0.24	0.48	0.84	9.6	0.6
3	200	10	45	500	0.66	0.66	1.32	7.2	1.5
4	500	6	30	500	0.18	0.78	0.84	4.8	3
5	500	8	40	100	7.2	1.2	2.4	4.2	0.72
6	500	10	45	200	5.4	0.48	4.2	8.4	0.84
7	900	6	30	200	0.54	0.36	0.84	6	1.8
8	900	8	40	500	0.24	0.9	2.16	4.2	0.96
9	900	10	45	100	6.6	5.4	3.6	9.9	0.6

Table 3. Calculation of Regression coefficients for MRR

Regression Coefficients	Al6061 +3% SiC	Al6061 +6% SiC	Al6061 +9% SiC	COPPER	BRASS
Constant	-28.5	6.36	7.18	-28.38	0.03
T_{ON}	-0.00687	-0.01539	-0.0107	0.0546	0.00439
I	-9.33	-1.87	3.32	-10.8	1.086
V	2.92	0.138	-0.78	3.2	-0.2058
T_{OFF}	0.0869	0.01246	-0.00889	-0.00615	0.01108
T_{ON}*T_{OFF}	0.000057	0.00001	0.000011	0.000022	
I* T_{OFF}	0.0585				-0.00111
V* T_{OFF}	-0.0155				
T_{ON} * I		0.00146	-0.00244	0.02768	
T_{ON}*V		0.00032	0.00074	-0.00735	-0.00012

The following Linear Mathematical model are generated using Minitab Software

Regression Equation For Metal Removal Rate

MRR**(Al6061+3%SiC)**=$-28.5 - 0.00687\ T_{ON} - 9.33I + 2.92\ V + 0.0869\ T_{OFF} + 0.000057\ T_{ON}{*}T_{OFF} + 0.0585\ I{*}\ T_{OFF} - 0.0155\ V{*}\ T_{OFF}$

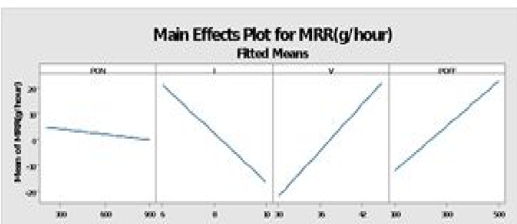
MRR**(Al6061+6%SiC)**= $6.36 - 0.01539\ T_{ON} - 1.87\ I + 0.138V + 0.01246\ T_{OFF} + 0.00146\ T_{ON} * I + 0.00032\ T_{ON}{*}V - 0.000024\ T_{ON}{*}\ T_{OFF}$

MRR**(Al6061+9%SiC)**= $7.18 - 0.0107\ T_{ON} + 3.32\ I - 0.78V - 0.00889\ T_{OFF} - 0.00244\ T_{ON} * I + 0.00074\ T_{ON}\ {*}V + 0.000011\ T_{ON}{*}\ T_{OFF}$

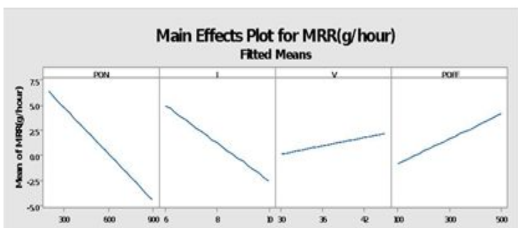
MRR **(Copper)** = $-28.38 + 0.0546\ T_{ON} - 10.80\ I + 3.200\ V - 0.00615\ T_{OFF} + 0.02768\ T_{ON} * I - 0.00735\ T_{ON}\ {*}V + 0.000022\ T_{ON} * T_{OFF}$

MRR**(Brass)** = $0.03 + 0.00439\ T_{ON} + 1.086\ I - 0.2058\ V + 0.01108\ T_{OFF} - 0.000124\ T_{ON}\ {*}V - 0.001109\ I{*}\ T_{OFF}$

Fig-4 Graphical Relation among Input and Output Relations

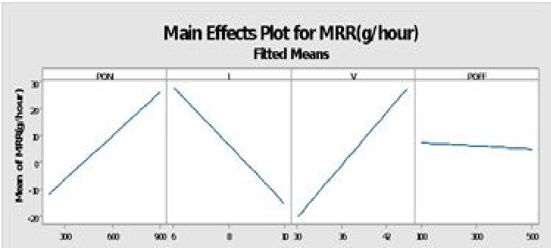


Al6061+3% SiC

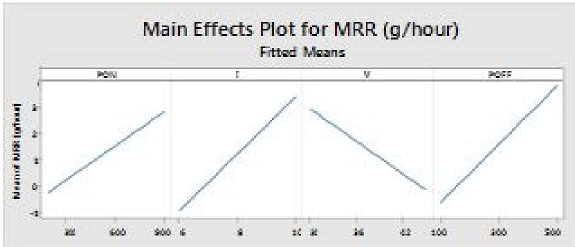


Al6061+6%SiC

Al6061+9%SiC

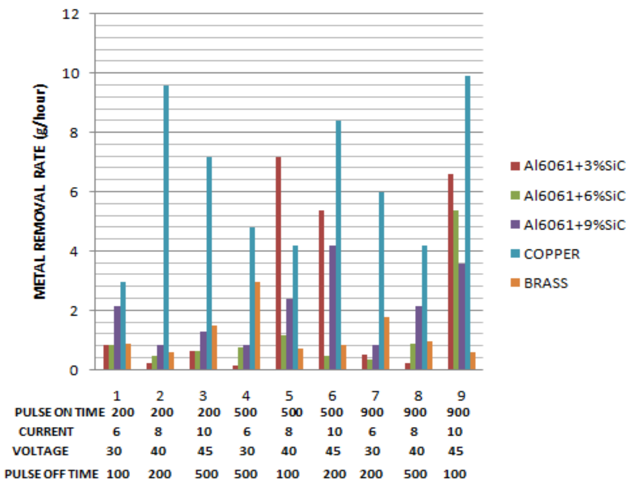


Copper



Brass

Fig-5 MRR Vs Input Parameters



Tool Wear Rate

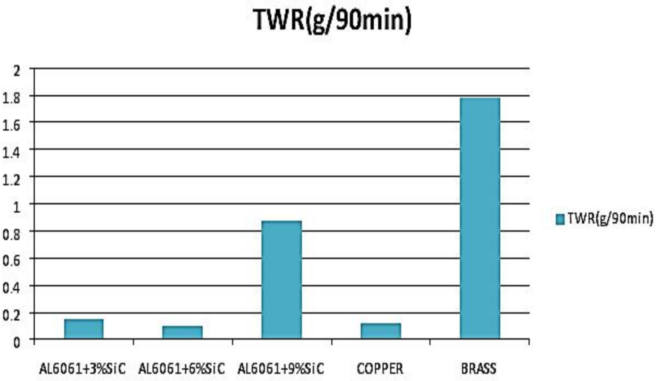
TWR is calculated as the proportion of the change of weight of the electrode tool before and after machining to the product of machining period and density of the tool materials.

$$\text{TWR} = \frac{electrodetoolwt.beforemachining - electrodetoolwt.\ aftermachining}{machiningtime}$$

Table 4. Calculated TWR for Al6061+SiC(3%,6%,9%), Copper & Brass Electrodes

TOOL	INITIAL WEIGHT	FINAL WEIGHT	TWR(kg/90min)	TWR(g/90min)	% TWR
Al6061+3%SiC	0.065698	0.065548	0.00015	0.15	4.9
Al6061+6%SiC	0.068798	0.068695	0.000103	0.103	3.4
Al6061+9%SiC	0.070563	0.069685	0.000878	0.878	28.9
COPPER	0.114983	0.114863	0.00012	0.12	3.9
BRASS	0.081645	0.079861	0.001784	1.784	58.7

Fig-6 Tool Wear Rate of Electrodes



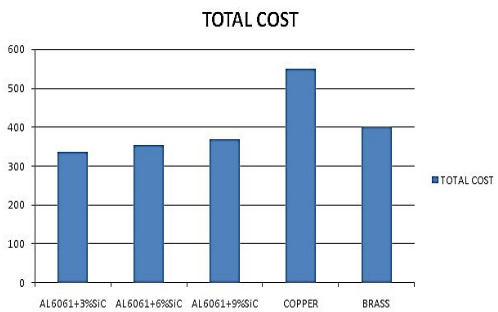
Cost Analysis

The following table gives the information about the unit cost of Electrode Material. It is seen from the table that Copper material has highest cost and Al6061 alloy with 3%SiC has Lowest cost.

Table 5.Cost Analysis for Al6061+SiC(3%,6%,9%), Copper & Brass Electrodes

TOOL	MATERAL COST (per kg)	MANUFACTURING COST	TOTAL COST
AL6061+3%SiC	266	70	336
AL6061+6%SiC	283	70	353
AL6061+9%SiC	300	70	370
COPPER	500	50	550
BRASS	350	50	400

Fig-7 Cost of Electrode Material



6. Results & Conclusions

The experiments were carried out by Taguchi methodology. The results obtained were recorded and the metal removal rate was calculated and the regression model in linear form is developed. The following conclusions are drafted from the work carried out.

- Al6061+ SiC (with SiC of 3%) tool has a maximum metal removal rate of 7.2 g/hour for a combination of input variables Pulse on time: 500µs, Current: 8A, Voltage: 40V, Pulse off time: 100µs.
- Al6061+ SiC (with SiC of 6%) tool has a maximum metal removal rate of 5.4 g/hour for a combination of input variables Pulse on time: 900µs, Current: 10A, Voltage: 45V, Pulse off time: 100µs.
- Al6061+ SiC (with SiC of 9%) tool had a maximum metal removal rate of 3.6 g/hour for a combination of input variables Pulse on time: 900µs, Current: 10A, Voltage: 45V, Pulse off time: 100µs.
- Copper Tool had a maximum metal removal rate of 9.9 g/hour for a combination of input variables Pulse on time: 900µs, Current: 10A, Voltage: 45V, Pulse off time: 100µs

- Brass Tool had a maximum metal removal rate of 3 g/hour for a combination of input variables Pulse on time: 500µs, Current: 6A, Voltage: 30V, Pulse off time: 500µs
- The tool wear rate is calculated for all the tools and it was found that the tool wear rate is minimum for Al6061+6% SiC of 0.103 g/90min with a percentage Tool wear rate of 3.4.
- The cost analysis has been performed and the Total cost (material cost + manufacturing cost) is calculated, the total cost is minimum for Al6061+3% SiC which is Rs.336.
- From the total observation the Life time of Tool is more for Al6061+SiC(with SiC of 6%) and Preparation of Tool cost is Rs.353.

7. References

[1] Sushil Kumar Choudhary (2014) Current Advanced Research Development of Electric Discharge Machining (EDM), International Journal of Research in Advent Technology, Vol.2, No.3 (E-ISSN:2321-9637) pg. 273-274

[2] K.H. Ho, S.T. Newman,State of the art electrical discharge machining (EDM), International Journal of Machine Tools & Manufacture 43 (2003) 1287–1300.

[3] Rao P. Srinivasa, Reddy Sidda B., Kumar JS and Reddy KVK, Fuzzy modelling for electrical discharge machining of AISI 304 stainless steel, Journal of Applied Sciences Research, 6(11) (2010): pp. 1687-1700.

[4] Tomadi SH, Hassan MA, Hamedon Z, Daud R, Khalid AG. Analysis of the influence of EDM parameters on surface quality, material removal rate and electrode wear of tungsten carbide. In Proceedings of the International MultiConference of Engineers and Computer Scientists 2009 Mar 18 (Vol. 2, pp. 18-20).

[5] Zhao Wansheng, Wang Zhenlong , Di Shichun, Chi Guanxin, Wei Hongyu "Ultrasonic and electric discharge machining to deep and small hole on titanium alloy." Journal of Materials Processing Technology 120 (2002) 101-106.

[6] UlasÇaydas& Ahmet Hasçalik, "Modeling and analysis of electrode wear and white layer thickness in die-sinking EDM process through response surface methodology", Int J Adv Manuf Technol (2008) 38:1148–1156.

[7] Z.Y. Yu, K. P. Rajurkar and H. Shen, "High Aspect Ratio and Complex Shaped Blind Micro Holes by Micro EDM" University of Nebraska-Lincoln, USA 2002.

[8] G. Appa Rao, Mahendra Kumar, M. Srinivas, D.S. Sarma "Effect of standard heat treatment on the microstructure and mechanical 2003.

[9] P. Kuppan& A. Rajadurai& S. Narayanan, "Influence of EDM process parameters in deep hole drilling of Inconel 718" Int J Adv Manuf Technol (2008) 38:74–84.properties of hot isostatically pressed superalloy inconel 718." Materials Science and Engineering A355 (2003) 114/125.

[10] Mr. V.D.Patel, Prof. C. P. Patel , Mr. U.J. Patel, Analysis of Different Tool Material On MRR and Surface Roughness of Mild Steel In EDM , International Journal of Engineering Research and Applications (IJERA) ISSN:2248-9622, Vol. 1, Issue 3, pp. 394-397.

[11] AnkurSrivastava,KumarAbhishek,Surav Datta, Chandramani Upadhyaya, Siba Sankar Mahapatra, Effect of variation of electrode material on machining performance of Al 6061 during EDM operation, Department of Mechanical Engineering FST, IFHE, Hyderabad,INDIA Department of Mechanical Engineering National Institute of Technology, Rourkela, Odisha, India.

[12] Manish Vishwakarma, V.K. Khare, Vishal Parashar, Response Surface approach for optimization of Sinker EDM process parameters on AISI 4140 alloy steel, International Journal of Engineering Research and Applications (IJERA), Volume 2, Issue 4, July-August 2012.

[13] Sandeep, Metal Removal Rate Optimization in Electric Discharge Machining Process , International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463 Vol. 3 Issue 10, October-2014.

[14] Prashant Yadava, Avdesh Chandra Dixit, Jitendra Kumar Verma, Optimization of EDM Parameter of High Carbon-High Chromium Steel (AISI D3) by using Brass Electrode,

IOP Conf. Series: Journal of Physics: Conf. Series **1455** (2020) 012021 doi:10.1088/1742-6596/1455/1/012021

International Journal of Engineering Trends and Technology (IJETT) – Volume 34 Number 3- April 2016 .

[15] P Shankar, R Boopathi and M Prabu, Investigating the Effect of Brass Electrode on Inconel 718 on Electrical Discharge Machine, IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 4, April 2015.

[16] Nayan Patel, Review on Importance of Electrodes in Electrical Discharge Machining Process, International Journal of Research in Aeronautical and Mechanical Engineering..

[17] Samruddhi Rao, Pragati Samant, AthiraKadampatta, Reshma Shenoy "An Overview Of Taguchi Method: Evolution, Concept and Interdisciplinary Applications", International Journal of Scientific and Engineering Research, 2013.

[18] Sorana D Bolboaca and Lorentz Jantschi, "Design of Experiments: Useful Orthogonal Arrays for Number of Experiments from 4 to 6", Entropy, Vol. 9, 2007, 198-232.

[19] Kuldeep OjhaR. K. Garg, K. K. Singh Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.8, pp.709-739, 2010 jmmce.org

[20] Arun Kumar, RP Swamy Evaluation of mechanical properties of Al6061, flyash and E-glass fiber reinforced hybrid metal matrix composites, 2011/5ARPN journal of engineering and applied sciencesVol.6,Issue5,40-44 .

[21] Ashwani Kharola, Analysis of Various machining parameters of EDM on Hard Steel using copper and Aluminium electrodes" (March 2015) have studied the process parameters on EDM using Copper, Aluminium electrodes and EN8 work material2015/3/1,IJEM,Vol.5,1-14 .

[22] J. Laxman and Dr.K.Gururaj in their journal "Modeling and Analysis of EDM process parameters using Taguchi technique and Fuzzy based modeling" International Journal of Advanced Mechanical Engineering.ISSN 2250-3234 Vol 4, Number 5(2014), pp. 473-480 .

[23] J.Jeevamalar and S. Ramabalan, Experimental Investigations into the Effect of Process Parameters on Performance Measures of Sink EDM Process: A Review Year 2011 To 2015and Future Work,(IJERT),ISSN: 2278-0181,IJERTV5IS010213Vol. 5 Issue 01, January-2016 .

[24] C. Mathalai Sundaram, R.Sivasubramanian, M.Sivakumar in their study on " An Experimental Investigation on Machining Parameters of Electrical Discharge Machining of OHNS Steel"(IJERT)Vol. 2 Issue 12, December – 2013.

[25] Ved Prakash Pandey, MrR.N.Mall in their study on "Analyis of material removal rate of AlSi 304 SS in EDM process" IJSRD ,Vol. 2, Issue 07, 2014| ISSN (online): 2321-0613

[26] Mehul G.Mehta, Nikul.K.Patel in their study on "Temperature and thermal stress analysis of EDM" (Jan-2014) Volume 03, Issue 01 , **Published (First Online):** 23-01-2014 **ISSN:** 2278-0181 **Publisher Name :** IJERT.

[27] Bhola Jha, K.Ram and Mohan Rao in their study on "An overview of technology and research in electrode design and manufacturing in sinking electrical discharge machining" Journal of Engineering Science and Technology Review 4 (2) (2011) 118-130