ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 6, June 2016

FINDING INFLUENCE PARAMETERS FOR MRR AND TWR DURING EDM OF EN-41 ALLOY BY TAGUCHI METHOD

MUBEEN[1], NAVDEEP MALHOTRA[2]

Abstract— *The present study analyze the relation of process parameters in electro-discharge of EN-41alloy steel with novel tool electrode material such as brass and copper, Taguchi method was employed with the help of Minitab-17 software for developing experimental models. Analysis on machining distinctive of electrical discharge machining (EDM) die sinking was made on the formulated models. In this study, Peak Current (Ip) amp, Spark on time (Ton) µs. Duty cycle (τ), Two Electrode (copper and brass) are considered as input process parameters. The process performances such as material removal rate (MRR) and tool wear rate (TWR) were standardize Analysis of variance test had also been carried out to check the adequacy of the formulated regression models. The observed optimal process parameter settings based on composite desirability. The optimized factor for MRR is Tool is Copper, Duty cycle (Ʈ) =9, Spark on time (ton) =500µs, Peak current=10 amp and For TWR the optimized factors are Tool is Brass, Peak current=10 amp. Spark on time (ton) =500 µs, duty cycle (Ʈ) =9 achieving maximum MRR and minimum TWR.*

Keywords
Tool Wear Rate (TWR), Material Removal Rate (MRR), Orthogonal Array (OA), Electrode Wear (EW), Electric Discharge Machine (EDM)

0. INTRODUCTION

Electric discharge machining (EDM) is a non- customary machining operating procedure in the manufacture of complex shaped dies, moulds and scathing parts used in automobile, aerospace, surgical and other industrial applications. Electrical-discharge machining (EDM) is extensively used for high strength materials. A major advantage of EDM is that the tool and the work piece do not come into contact, in this process material is removed by controlled erosion through a series of electric sparks between the tool (electrode) and the work piece. The thermal energy of the sparks leads to intense heat conditions on the work piece causing melting and vaporizing of work piece material. Due to the high temperature of the sparks, not only work material is melted and vaporized, but the electrode material is also melted and vaporized, which is known as electrode wear (EW). The EW process is quite similar to the material removal mechanism as the electrode and the work piece are considered as a set of electrodes in EDM. Due to this wear, electrodes lose their dimensions resulting in inaccuracy of the cavities formed. During EDM, the main output parameters are the material removal rate (MRR), Tool wear ratio (TWR), EN-41 is the most preferred material for forging components consequently; an analysis on the influence of current and pulse duration and duty cycle over MRR and TWR was performed. EDM is now unquestionably recognized as an important precision machine tool forming process for producing internal shapes on work piece, this study present experimental analysis based on four factors and two levels (23) OA L8design. The objective of this research is to study the performance of different electrode materials on EN-41 work piece with EDM

Principle of EDM:

The principle of EDM is to use the eroding effect of controlled electric spark discharges on the electrodes. It is thus a thermal erosion process. The sparks are created in a dielectric liquid, generally water or oil, between the work piece and an electrode, which can be considered as the cutting tool. There is no mechanical contact between the electrodes during the whole process. Since erosion produced by electrical discharges, both electrode and work piece have to be electrically conductive. Thus, the machining process consists in successively removing small volumes of work piece material, molten or vaporized during a discharge. The volume removed by a single spark is small, in the range of 10^{-6}-10^{-4} mm^3 but this basic process is repeated typically 10,000 times per second.

First, voltage is applied between the electrodes. This ignition voltage is typically 200 V. The breakdown of the dielectric is initiated by moving the electrode towards the work piece. This will increase the electric field in the gap, until it reaches the necessary value for breakdown. The location of breakdown is generally between the closest points of the electrode and of the work piece, but it will also depend on particles present in the gap. When breakdown occurs, the voltage falls and a current rises abruptly the presence of a current is possible at this stage, because the dielectric has been ionized and a plasma channel has been created between the electrodes.

2. LITERATURE REVIEW:

The literature contains a good body of knowledge on the research of metal removal rate, tool wear rate, surface roughness, radial overcut, surface integrity characteristics etc. in the past related to electric discharge machining process. In order to develop and optimize Metal removal rate, tool wear rate, surface roughness, it is essential to understand the current status work in this area. The need for selecting and establishing optimal machining condition and most suitable machining tools has been felt past over a few decades. The MRR, TWR, surface quality is an important factor to evaluate the productivity of machined component as well as machine tools. A reasonably good surface finish is required for improving the fatigue strength, aesthetic appeal and corrosion resistance of the product.

B. H. Yan, C. C. Wang,(2000)*work optimizes the cutting of Al2O3/6061Al composite using rotary electro-discharging machining (EDM) with a disk like electrode by using Taguchi methodology. The Taguchi method is used to formulate the experimental layout, to analyze the effect of each EDM parameter on the machining characteristics, and to predict the optimal choice for each EDM parameter. This work evaluates the feasibility of machining Al2O3/6061Alcomposite by rotary EDM with a disk like electrode. Based on the results presented herein, we can conclude the following:- 1. the machining process of the Al2O3/6061Al composite by rotary EDM with a disk like electrode is feasible in comparison with other machining process. 2. Rotary EDM with a dislike electrode is shown from the observed results to reach a higher MRR although the EWR is higher. The overall advantage still makes this revised technology an acceptable tool.*

Ali Ozgedik & Can Cogun et.al (2006) Ali *the variations of edge and front wear characteristics as well as machining performance outputs like work piece removal rate, tool wear rate, relative wear and work piece surface roughness, are effected by various dielectric flushing methods, discharge current and pulse duration setting.*

A. A. Khan et.al (2008) *reported that aluminum and mild steel shows more material removal with increase in current, the highest MRR was obtained during machining of aluminum using a brass electrode, EW increases with increase in current and voltage. Wear of copper electrodes is less than that of brass electrodes.*

K. D. Chattopadhyay &P. S. Satsangi &S. Verma &P. C. Sharma et.al (2008) *Rotary electrical discharge machining in induced magnetic field produced higher material removal rate and decreases electrode wear rate as compared with machining in a non-magnetic field and Reduction in EWR, helps in achieving higher geometric trueness, resulting in better dimensional control on the work piece.*

Jong Hyuk Jung and Won Tae Kwon et.al (2010)*optimal machining conditions for drilling of a micro-hole of minimum diameter and maximum aspect ratio It was found that the electrode wear and the entrance and exit clearances have a significant effect on the diameter of the micro-hole when the diameter of the electrode is identical. To determine the machining parameters affecting the electrode wear and the entrance and exit clearances, Grey relational analysis was used. The input voltage and the capacitance were found to be the most significant controlling parameters.*

Pravin R. Kubade, V. S. Jadhav (2012) *investigated the influence of EDM parameters on EWR, MRR and ROC in machining of AISI D3 material. The parameters considered were pulse on-time (Ton), peak current (Ip), duty factor (t) and gap voltage (Vg). The experiments were performed on the die-sinking EDM machine fitted with a copper electrode. The experiments were planned, conducted and analyzed using Taguchi method. It is found that the MRR is mainly influenced by peak current where as other factors like Pulse on-time , gap voltage have very less effect on material removal rate. Electrode wear rate is mainly influenced by peak current (Ip) and pulse on-time (Ton), duty cycle (t) and gap voltage (Vg) has very less effect on electrode wear rate. Peak current (Ip) has the most influence on radial overcut then followed by duty cycle (t) and pulse on time (Ton) with almost very less influence by gap voltage (Vg).*

Hitesh B Prajapati, V.A.Patel, Hiren R Prajapati(2012) *studied the performance of different electrode Materials on EN-9 work piece with EDM process based on Full Factorial Design . The electrode materials were graphite, copper and Brass. The important parameters to be optimized were peak current, pulse on-time, pulse off-time. The result of experiment suggests that the Graphite electrode gives higher MRR than other two Electrodes. Brass electrode gives better surface finishing among three electrodes. Powder electrode gives the better MRR and high SR more than solid electrode.*

M. Durairaja, D. Sudharsun (2013) *summarize the Grey relational theory and Taguchi optimization technique, in order to optimize the cutting parameters in Wire EDM for SS304. The objective of optimization is to attain the minimum kerfs width and the best surface quality simultaneously and separately. In this present study stainless steel 304 is used as a work piece, brass wire of 0.25 mm diameter used as a tool and distilled water is used as dielectric fluid. For experimentation Taguchi L16 orthogonal array has been used. The input parameters selected for optimization are gap voltage, wire feed, pulse on-time and pulse off-time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters.*

Experimental investigation on wire electrical discharge machining of Stainless Steel (SS304) has been done using brass wire of 0.25mm. The following conclusions are made. Based on Taguchi optimization method, the optimized input parameter combinations to get the minimum surface roughness are 40V gap voltage, 2mm/min wire feed, 6 µs pulse on-time, 10 µs pulse off-time and similarly optimized conditions to get the minimum kerfs width are 50V gap voltage, 2mm/min

M Manohara and T Selvaraj (2014) *experiment was perform on Inconel 718 with include identification of factors that are to be included in the experiments and determining their levels for varying. Accordingly the process parameters namely, Peak Current (A), Pulse on-time (µs) and Pulse off-time (µs), applied voltage, and Flushing pressure were for considered the study.*

Output parameters chosen for assessing the process performance were machining time, electrode wear rate, recast layer and surface topography. Based on the surface roughness measured on the machined surface, optimum set of process parameters was arrived as, Current =12 A, On-time =400 µs, Off -time =40 µs .

B.Singarvel, T.Selvaraj (2014) *in this experimental analysis the optimum machining parameters are estimated using*

Taguchi based utility concept coupled with Principal Component Analysis (PCA) on turning of EN25 steel with CVD and PVD coated carbide tools. This method has been employed for simultaneous minimization of surface roughness, cutting force and maximization of material removal rate. The multi S/N ratio is achieved by the product of weight factor and S/N ratio to the performance characteristics in the utility concept. Principal component analysis is adopted to find the weight factors involved for all objectives The Taguchi's utility concept coupled with PCA is found to be very simple method used for simultaneous minimization of surface roughness, cutting force and maximization of metal removal rate. Principal Component Analysis is successfully employed for the estimation of weight factors involved for all objectives.

***Murahari Kolli, Adepu Kumar (2015)** in this paper, Taguchi method was employed to optimize the surfactant and graphite powder concentration in dielectric fluid for the machining of Ti-6Al-4V using Electrical Discharge Machining (EDM). The process parameters such as discharge current, surfactant concentration and powder concentration were changed to explore their effects on Material Removal Rate (MRR), Surface Roughness (SR), Tool wear rate (TWR) and Recast Layer Thickness (RLT). Detailed analysis of structural features of machined surface was carried out using Scanning Electron Microscope (SEM) to observe the influence of surfactant and graphite powder on the machining process. The practical benefit of this study is that the uses of obtained optimum condition improves the material removal rate, reduces surface roughness and lessen the recast layer of Titanium alloy. Material removal rate at optimum condition (i.e. A3B2C3) is increased with increase in the discharge current and graphite powder concentration. As the surfactant concentration increases from 4 to 6 g/lit, MRR increases, beyond 6 g/lit MRR decreases.*

***Krishna Kumar Saxena, Sanjay Agarwal (2016)** the experimentation was planned using Taguchi's L9 theory. A combination of scanning electron microscopy (SEM), white light interferometer (WLI), energy dispersive x-ray spectroscopy (EDX), atomic force microscopy (AFM) and X-ray diffraction (XRD) was used to characterize the machined surface and study the material removal and material migration mechanism. It was found that improved characterization and understanding of micro-EDM can lead to better micro-machining of conductive SiC. Micro-EDM operation was performed on SiC. Machining of micro depth is emphasized high magnification SEM images and simulation study clarified the material removal mechanism to the melting and evaporation due to intense localized heating. A combination of SEM and EDX analysis revealed the material migration to be bidirectional.*

***Ryota Toshimitsu, Akira Okada (2016)** EDM machined surface using metal powder mixed fluids sometimes have high surface functions such as high hardness, high corrosion resistance and so on. Therefore, the high functional EDM finished surface is well expected to be applied as a final metal mold surface. In this study, formation of chromium containing layer on the EDM machined surface was tried by using chromium powder mixed fluid. Furthermore, the EDM machined surface characteristics with chromium powder mixed fluid were experimentally evaluated. Main conclusions obtained are as follows, chromium containing layer can be formed on the EDM finished surface by using a chromium powder mixed fluid. Small surface roughness can be obtained by EDM finishing in CrPMF when CrPMF is sufficiently stirred. The chromium content on the EDM finished surface increases when discharge current is low and chromium powder concentration is high. The chromium containing layer becomes thick when discharge current and chromium powder concentration are high. The Vickers hardness, water repellency and corrosion resistance of EDM finished surface can be increased by using chromium powder mixed fluid.*

3. EXPERIMENTAL SET-UP AND SELECTION OF PROCESS PARAMETERS:

The experiments were conducted using the Electric Discharge Machine, model ELECTRONICA SE-35 Electra Plus 500 x300 (die sinking type) the polarity of the electrode was set as positive while that of work piece was negative. The dielectric fluid used was EDM oil-30 (specific gravity-0.763). The EDM consists of the following parts:
(i)Dielectric reservoir, pump and circulation system.
(ii)Power generator and control unit.
(iii)Working tank with work holding device
(iv) X-Y working table
(v)The tool holder
(vi)The servo system for feeding the tool.

4. MATERIAL:

The electrode materials used are copper and brass. The chemical composition of electrode materials which is show in Table 1.

Table 1:- Chemical composition of Electrode materials

Composition In %	Copper	Brass
Copper	99.750	56.700
Aluminum	0.040	0.025
Tin	0.030	0.020
Phosphorous	0.030	0.020
Lead	0.009	3.000
Iron	0.015	0.100
Zinc	0.060	39.850
Nickel	0.010	0.0770

Table 2:- Major Properties of Electrode Materials

Electrode materials	Thermal conductivity (W/m-°K)	Melting point (°C)	Electrical resistivity (ohm-cm)	Specific heat capacity (J/g-°C)
Copper	391	1,083	1.69	0.385
Brass	159	990	4.7	0.38

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 6, June 2016

Properties of electrode material:-

(i)High electrical conductivity – electrons are cold emitted more easily and thus there should less bulk electrical heating.

(ii)High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear.

(iii)Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy.

(iv)High melting point – high melting point leads less tool wear because of less tool material melting for the same heat load.

4.1 Work Piece Material

The work material was EN-41. The chemical composition of EN-41 which is show in Table 2 and having hardness 263BHN and 26 HRC which was tested on the Vickers machine.

Table 3 Composition of EN-41

Composition In %	*Copper*	*Brass*
Copper	*99.750*	*56.700*
Aluminum	*0.040*	*0.025*
Tin	*0.030*	*0.020*
Phosphorous	*0.030*	*0.020*
Lead	*0.009*	*3.000*
Iron	*0.015*	*0.100*
Zinc	*0.060*	*39.850*
Nickel	*0.010*	*0.0770*

5. DESIGN OF EXPERIMENTS:

5.1 Taguchi Method:

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process of design that focuses on minimizing the variation and maximizing sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. Taguchi proposed several approaches to the experimental designs that are sometimes called "Taguchi Methods." These methods utilize two-, three-, four-, five-, and mixed-level fractional factorial designs.

5.2 Signal to Noise Ratio:

Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It is observed that on target performance usually satisfies the user best, and the target lies under acceptable range of product quality are often inadequate. If Y is the performance characteristic measured on a continuous scale when ideal or target performance is T then according to Taguchi the loss caused L(Y) can be modeled by a quadratic function as shown in equation(1)

$L(Y) = K(Y - T^2)$ ……………………… **(1)**

The objective of robust design is specific; robust design seeks optimum settings of parameters to achieve a particular target performance value under the most noise condition. Suppose that in a set of statistical experiment one finds a average quality characteristic to be μ and standard deviation to be σ. Let desired performance be $\mu 1$ .The goal the loss after adjustment is due to variability remaining from the new standard deviation. Loss after adjustment shown in equation.

Table I: Response table of MRR & TWR

S. N O	*Duty Cycle*	*Current*	*Spark on time*	*Tool Material*	*MRR*	*TWR*
1	*9*	*5*	*500*	*Copper*	*0.0279*	*0.0011*
2	*9*	*5*	*1000*	*Brass*	*0.0183*	*0.0034*
3	*9*	*10*	*500*	*Brass*	*0.035*	*0.0074*
4	*9*	*10*	*1000*	*Copper*	*0.038*	*0.0025*
5	*10*	*5*	*500*	*Brass*	*0.0294*	*0.0195*
6	*10*	*5*	*1000*	*Copper*	*0.03*	*0.0022*
7	*10*	*10*	*500*	*Copper*	*0.0478*	*0.0112*
8	*10*	*10*	*1000*	*Brass*	*0.0346*	*0.019*

The case of MRR, it is "Larger is better", so from this table it is clearly definite that current is the most important factor then material , pulse on time and at last duty cycle. During the process of Electrical discharge machining, the influence of various machining parameter like I_p, Tool material, Duty Cycle has significant effect on MRR, as shown in the main effect plot for S/N ratio of MRR in Figure 1. The discharge current (Ip) is directly proportional to MRR in the range of 5 to 10A. This is expected because an increase in pulse current produces strong spark, which produces the higher temperature, causing more material to melt and erode from the work piece. Besides, it is clearly evident that the spark on time factor does not influence much as compared to tool material and duty cycle similar conclusions were shown. However, MRR decreases monotonically with the increase in pulse on-time. The spark on-time has no significant effect on MRR.

Table II: Response Table for Signal to Noise Ratios Larger is better

Level	**TOOL MATERIAL**	**SPARK ON TIME**	**CURRENT**	**DUTY CYCLE**
1	-30.93	-29.31	-31.73	-30.84
2	-29.09	-30.71	-28.29	-29.18
Delta	1.84	1.4	3.44	1.66
Rank	**2**	**4**	**1**	**3**

RESULTAND DISCUSSION:

LB denotes the S/N ratios calculated from observed values, yi represents the experimentally observed value of the i^{th} experiment and n=1 is the repeated number of each experiment in L-8 OA is conducted. The analysis of variances for the factors is shown in Table III which is clearly indicates that the duty cycle is not important for influencing MRR Ton and Ip, material are the most influencing factors for MRR .The delta values are current, tool material ,duty cycle and spark on time are 3.44 , 1.84,1.66 and 1.4 respectively, depicted in Table II.

7. CONCLUSION:

The results reveal that the primary factor affecting the MRR is peak current subsequently followed by material, duty cycle and pulse on-time.

In case of TWR the primary factor affecting TWR is material then duty cycle and current at last spark on-time.

The optimized factor for MRR is cupper, duty cycle (t) =10, pulse on-time=500µs, peak current=10amp.

For TWR the optimized factors are brass, peak current=10amp, pulse on time (ton) =500µs, duty cycle (t) =10.

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