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An Experimental Investigation on Machining Parameters of Electrical Discharge Machining of OHNS Steel

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Abstract

*Presently manufacturing industries are facing various challenges from these advanced materials viz. super alloys, ceramics, and composites, whose mechanical properties are hard and difficult to machine. It requires high precision, surface quality which increases machining cost. To meet these technological challenges, non-conventional machining processes are being employed to achieve higher metal removal rate, better surface finish and greater dimensional accuracy, with less tool wear. Electric Discharge Machining (EDM) is a non-conventional process and has a wide applications in automotive, defense, aerospace and micro systems industries plays an excellent role in the development of cost effective products with more reliable quality assurance. Here we report and analyse the various parameters in Electrical Discharge Machining. Experimental results are discussed on electric discharge machining of OHNS (*Oil Hardening non Shrinking Tool Steel) *Die material in Copper and Aluminium electrode. Statistical analysis is presented to identify the effect of process input factors (viz. current, voltage) on the output factors viz. Material Removal Rate (MRR), Electrode Wear Rate (EWR).*

Keyword- *Electrical discharge machining (EDM), Material removal rate (MRR), Tool wear rate (TWR),* Oil Hardening non Shrinking Tool Steel *(OHNS*), Percentage of Wear Rate (PWR*).*

1. Introduction

EDM is a non-traditional process that is used to remove metal through the action of an electrical discharge of short duration and high current intensity between the tool electrode and the work piece. There are no physical cutting forces between the tool and the work piece. This process is finding an increase in demand owing to its ability to produce geometrical complex shapes as well as its ability to machine hard materials that are extremely difficult to machine when using conventional process. In this study, the Electrical discharge machining of OHNS Die materials with Copper and Aluminum electrode are conducted and the graphical & analytical studies were done.

The Experimental results are going to use our further research progress in near future. The machining parameters MRR, TWR are going taken in to the analysis of a newly developed composite electrode made through powder metallurgy (PM) technique.

Naveen Beri S. Maheshwari, et., al [1] reported the performance Evaluation of Powder Metallurgy Electrode in EDM of AISI D2 Steel. Experimental results are presented on electric discharge machining of AISI D2 steel in kerosene with copper tungsten (30% Cu and 70% W) tool electrode made through powder metallurgy (PM) technique and Cu electrode.

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M. S. Reza M. Hamdi et.,al [2] has deliberated the Optimization of Control Parameters for EWR in injection Flushing Type of EDM on Stainless Steel 304. The operating control parameters of injection flushing type of electrical discharge machining process on stainless steel 304 work piece using copper tools are being optimized according to its individual machining characteristic i.e. Electrode Wear Ratio (EWR). Higher EWR would give bad dimensional precision for the EDM machined work piece because of high electrode wear.

M.R.Shabgard and R.M.Shotorbani [3] has developed the Mathematical Modeling of Machining Parameters in Electrical Discharge Machining of FW4 Welded Steel.

Here a mathematical models for relating the Material Removal Rate (MRR), Tool Wear Ratio (TWR) and surface roughness (Ra) to machining parameters (current, pulse-on time and voltage) was developed.

Katsushi Furutania et al [4] has studied the accretion of titanium carbide by electrical discharge machining with powder suspended in working fluid. A surface modification method by electrical discharge machining (EDM) with a green compact electrode has been studied to make thick TiC or WC layer. Titanium alloy powder or tungsten powder is supplied from the green compact electrode and adheres on a work piece by the heat caused by discharge. To avoid the Production process of the green compact electrode, a surface modification method by EDM with powder suspended in working fluid is proposed in this paper.

Krishna Mohana Rao G and D. Hanumantha Rao [5] have developed Hybrid Modelling and Optimization of Hardness of surface produced by Electric Discharge Machining using Artificial Neural Networks and Genetic Algorithm. The optimization of the hardness of surface produced in die sinking electric discharge machining (EDM) by considering the simultaneous affect of various input parameters.

Kathiresan M and T. Sornakumar [6] have studied EDM Studies on Aluminum Alloy-Silicon Carbide Composites Developed by Vortex Technique and Pressure Die Casting. The aluminum alloy-silicon carbide composites were developed using a new combination of vortex method and pressure die casting technique. Electrical Discharge Machining (EDM) studies were conducted on the aluminum alloy-silicon carbide composite work piece using a copper electrode in an Electrical Discharge Machine.

S.H.Tomadi , M.A.Hassan, and Z. Hamedon, [7] has prejudiced the Analysis of the EDM Parameters on Surface Quality, Material Removal Rate and Electrode Wear of Tungsten Carbide. Machining characteristics such as surface quality, material removal rate and electrode wear were studied. It is followed by optimizing the machining condition for confirmation test purposes.

Shruti Mehta ,. Avadhoot Rajurkar, and Jignesh Chauhan [8] reviewed on Current Research Trends in Die- Sinking Electrical Discharge Machining of Conductive Ceramics, the development of conductive ceramic materials followed by the progress of EDM technology in this context from its initiation to present state. The discussion is extended to key research areas such as optimizing the material removal, monitoring electrode wear, effect on surface quality. The present and prospering application ranges of such materials are also accounted for.

S. Prabhu and B.K. Vinayagam. [9] has analyzed the Surface Characteristics of AISI D2 Tool Steel Material Using Carbon Nano Tube. Carbon Nano tube is having high Mechanical and Electrical Properties specifically High Electrical Conductivity. By using this property the multi wall carbon Nano tube mixed with electrolytic solution in EDM process to analysis the surface characteristics like micro cracks, surface topography, and electrode wear and material removal rate in AISI D2 tool steel work piece materials which is very much used in moulds and dies.

Also the author describes the effect of Graphite Electrode Material on EDM of AISI D2 Tool Steel with Multiwall Carbon Nano tube Using Regression Analysis [10]. In the development of predictive models, machining parameters of Pulse current, Pulse on duration, voltage were considered as model variables. For this purpose, Analysis of variance (ANOVA) and *F*-test were used to check the validity of regression model and to determine the significant parameter affecting the surface roughness.

2. Machining Characteristics

The performance of EDM, regardless of the type of the electrode material and dielectric fluid is measured usually by the following criteria:

- Metal removal rate (MRR)
- Resistance to wear or electrode wear (EWR)

The following equation is used to determine the MRR value;

$$MRR = \frac{W_b - W_a}{t_m} \quad \text{(g/min)}$$

Where,

W_b = weight of work piece material before machining (g)
W_a = weight of work piece material after machining (g)
t_m = machining times (min)

This method is also adopted by Puertas and Perez (2003) and Puertas [11] and many other researchers. Maximum of MRR is an important indicator of the efficiency and cost effectiveness of the EDM process, however increasing MRR is not always desirable for all applications since this may scarify the surface integrity of the work piece. A rough surface finish is the outcome of fast removal rates.

In term of the EWR value, the equation below is usually used;

$$EWR = \frac{Weight\ \ of\ \ Electrode\ \ loss(g)}{Machining\ \ Time\ \ (\mathrm{min})}$$

3. Design Variables

The design variables are described into two main groups, which are response parameters and machining parameters.

1. Response Parameters

The response parameters include:

a. Material removal rate (MRR)
b. Electrode wear rate (EWR)

2. Machining Parameters

The parameters that are involved in this study are shown in Table 3.1

TABLE 3.1
MACHINING PARAMETERS

Variables	**Set – up**
Work piece	OHNS Die steel Block Size : 230 x 125 x 25 mm
Tool electrode	Copper & Aluminium (ϕ30 mm)
Polarity	Positive and negative (EDM process)
Voltage (V)	40 - 48
Current (A)	6 – 18
Dielectric Fluid	Kerosene
Flushing	Jet flushing

A. OHNS DIE STEEL

The work piece material is OHNS die material, which is also known as oil hardened non-shrinking steel. Dimensions of this steel are designed and accurately calculated. In compliance with high industry standards, it comes in form of round and flat steel. These contain 0.9 – 1.1% carbon, 0.5 – 2 % tungsten and 0.45 – 1% carbon. These are used for fine parts such as taps, hand reamers, milling cutters, engraving tools and intricate press tools which cannot be ground after hardening.

Fig 3.1 OHNS Die Steel (Work Piece) after machining

TABLE 3.2
CHEMICAL COMPOSITION OF OHNS DIE STEEL

Carbon	**Chromium**	**Tungsten**	**Iron**
0.9 - 1.3%	0.5%	0.4 - 0.8%	rest

B. COPPER

It is one of the most widely used non-ferrous metals in industry. Copper is soft and ductile that is difficult to machine and also it has an almost unlimited capacity to be cold-worked. Furthermore, it is highly resistant to corrosion in diverse environments including ambient atmosphere, sea water and some industrial chemicals. The mechanical and corrosion resistance properties can be improved by alloying.

Fig 3.2 Copper Electrode

TABLE 3.3
PROPERTIES OF COPPER

Physical properties	**Copper**
Density(g/cm^3)	8.94
Electrical Conductivity [(Ω-m) $^{-1}$x10 ^{6}]	58
Thermal Conductivity (W/m – K)	398
Coefficient of thermal expansion [×10^{-6} (1/°C)]	16.5
Melting Temperature [°C]	1085

C. ALUMINIUM

Aluminium and its alloys are characterized by a relatively low density (2.7 g/cm) as compared 7.9 g/ cm for steel, high electrical and thermal conductivities, and a resistance to corrosion in some environments, including the ambient atmosphere.

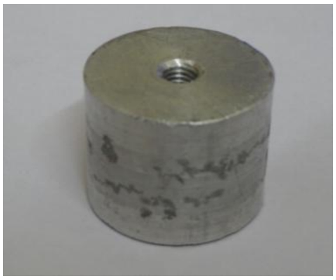

Fig 3.3 Aluminium Electrode

The mechanical strength of aluminium may be enhanced by cold work and by alloying. However both processes tend to diminish resistance to corrosion.

TABLE 3.4
PROPERTIES OF ALUMINIUM

Physical properties	Aluminium
Density(g/cm^3)	2.71
Electrical Conductivity [(Ω-m) $^{-1}$x10 ^{6}]	36
Thermal Conductivity (W/m – K)	231
Coefficient of thermal expansion [×10^{-6} (1/°C)]	23.6
Melting Temperature [°C]	646-657

4. Experimental Process

In our investigation, we used OHNS Die material as a target material and the material related properties are shown in Table 3.2. Experiments were performed using a SPARKONICS Electric Discharge Machine.

Fig 4.2 depicts schematically the experimental set up. A copper and aluminium electrodes with a diameter of 25 mm were used as an electrode to erode a work piece of OHNS Die material. Kerosene was used as a dielectric fluid in this experiment. Diameter of electrode and thickness of work piece is measured by digimatic micrometer. (Make: Mitutoyo, Least count: 0.001 mm). Weight of work piece is measured by Precisa - make weighing machine (Accuracy: 0.1mg).

Principle of EDM:-

Electric discharge machining is a controlled metal removing technique whereby an electric spark is used to cut the work piece, which takes a shape opposite to that of the cutting tool or electrode. The electrode is made from electrically conductive material. The electrode, made to the shape of the cavity required, and the work pieces are both submerged in a dielectric fluid. Dielectric fluid should be nonconductor of electricity. A servo mechanism maintains a gap of about 0.01 to 0.02mm between the electrode & the work piece, preventing them from coming into contact with each other.

A direct current of low voltage & high amperage is delivered to the electrode at the rate of approximately 50 KHz. These electrical energy impulses vaporize the oil at this point. This permits the spark to jump the gap between the electrode and the work piece through the dielectric fluid. Intense heat is created in the localized area of the spark impact, the metal melts and a small particle of molten metal is expelled from the surface of the work piece.

Figure 4.1 Sparkonix CNC EDM

Figure 4.2 EDM tank with electrode and work piece

The dielectric fluid which is constantly being circulated carries away the eroded particles of metal during the off cycle of the pulse and also assists in dissipating the heat caused by the spark. Table 4.1 shows the EDM Specifications.

TABLE 4.1
EDM SPECIFICATIONS

Optimum working current of pulse generator	15 amps
Tank size and capacity	500×300×200 mm 100 lits
Table size	300×200 mm
Longitudinal and cross travel	150×100 mm
Servo head vertical travel	150 mm

Servo Mechanism:- It is important that there is no physical contact between electrode & work piece, otherwise both electrode & work piece will be damaged. Electro discharge machines are equipped with a servo control mechanism that automatically maintains a constant gap of 0.01mm to 0.02mm between the electrode & work piece. If the gap is too large, ionization of the dielectric fluid does not occur and machining cannot take place. If the gap is too small, the tool and the work piece may weld together. Servo feed control mechanisms can be used to control the vertical movement of the electrode for sinking cavities.

Fig. 4.2 & 4.3 shows the schematic representation of EDM process.

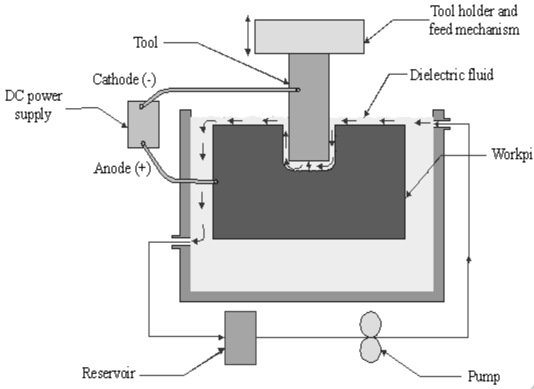

Figure 4.3 Schematic representation of EDM process

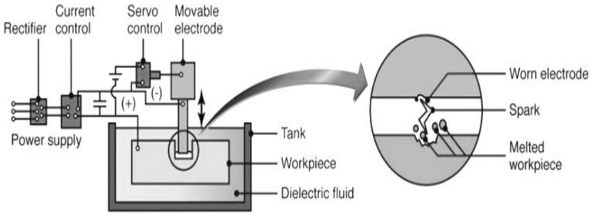

Figure 4.4 Schematic view of the Electrical-discharge machining process

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5. Results and Discussion

We have performed eight experiments on OHNS Die steel by using copper & aluminium tool electrode. At the end of each experiment; calculations were done for MRR, TWR and Percentage WR. The variations of all the four output parameters are plotted against the variable input parameters.

TABLE 5.1
PARAMETRIC VARIATION CHART

Exp No.	Current (A)	Voltage (V)	Pulse on time (µs)	Duty cycle	Flushing Pressure (pa)
1	6	40	6	12	0.5
2	10	40	6	12	0.5
3	14	40	6	12	0.5
4	18	40	6	12	0.5
5	14	42	6	12	0.5
6	14	44	6	12	0.5
7	14	46	6	12	0.5
8	14	48	6	12	0.5

TABLE 5.2
OBSERVATIONS IN EACH EXPERIMENT
(COPPER ELECTRODE)

Exp. No.	Work iece weight loss (g)	Electrode Weight Loss (g)	Time of cut (min)	MRR (g/min)	TWR (g/min)	% WR
1	3	2	20	0.15	0.1	66
2	4	2	20	0.2	0.1	50
3	6	3	20	0.3	0.15	50
4	7	4	20	0.35	0.2	57
5	8	2	20	0.4	0.1	25
6	10	3	20	0.5	0.15	30
7	12	2	20	0.6	0.1	16
8	15	3	20	0.75	0.15	20

TABLE 5.3
OBSERVATIONS IN EACH EXPERIMENT
(ALUMINIUM ELECTRODE)

Exp. No.	Work iece weight loss (g)	Electrode Weight Loss (g)	Time of cut (min)	MRR (g/min)	TWR (g/min)	% WR
1	3	2	20	0.15	0.1	66
2	5	3	20	0.25	0.15	60
3	6	2	20	0.3	0.1	33
4	7	2	20	0.35	0.1	28
5	9	3	20	0.45	0.15	33
6	11	3	20	0.55	0.15	27
7	12	3	20	0.6	0.15	25
8	14	2	20	0.7	0.1	14

5.1. Analysis of MRR, TWR, %WR vs Current – Copper Electrode

Amount of power used in EDM, is measured in terms of its amperage, and is termed as most important machining parameter in MRR. It is observed that with an increase in current, MRR improves up to 18 amperes (Fig.5.1).

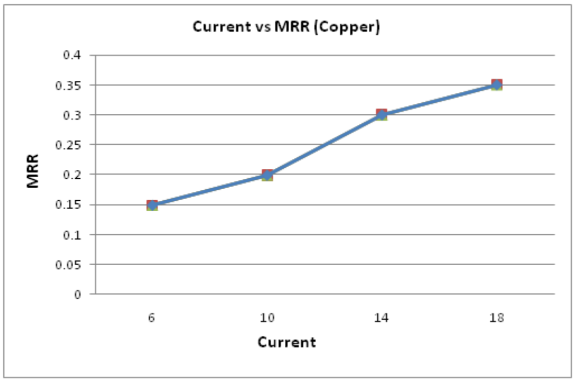

Fig.5.1 Graph of Current Vs MRR for Copper Electrode

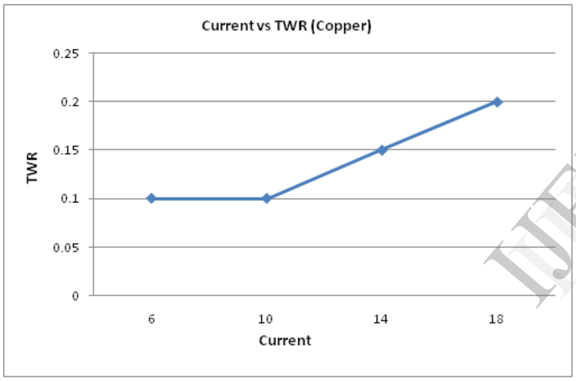

Fig.5.2 Graph of Current Vs TWR for Copper Electrode

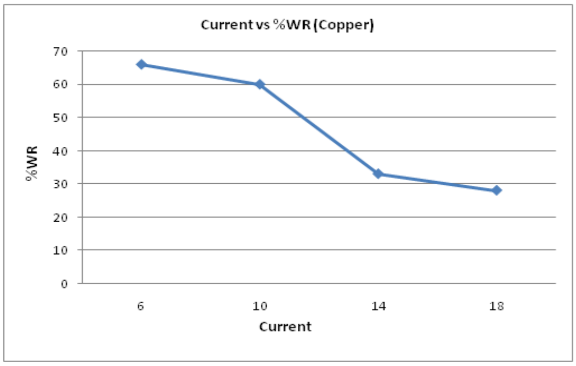

Fig. 5.3 Graph of Current Vs %WR for Copper Electrode

This can be explained as initially with increase in current MRR increases because of higher erosion of work piece material with increase in current.

It is observed that TWR increases with increase in current, as shown in (Fig. 5.2) because the current increases higher energy is available for the electrode wear. This causes more and more erosion of tool material with increase in current

It is observed that with an increase in current upto18ampers, Percentage WR decreases and then with further increase in current Percentage WR increases as shown in (Fig. 5.3).

These variations in trend can be explained with increase in current up to 18 amperes rate of tool wear is less as compared to material removal hence downward trend of the curve. After 18 amperes due to net deposition on work piece material from powder metallurgy electrode results in higher TWR as compared to MRR. Therefore curve has an upward trend.

5.2 Analysis of MRR, TWR, %WR vs Voltage – Copper Electrode

MRR increases by increasing open circuit voltage because electric field strength increases. It is observed that with an increase in voltage, MRR improves up to 60Volts and then starts to decrease continuously as depicted in (Fig. 5.4).

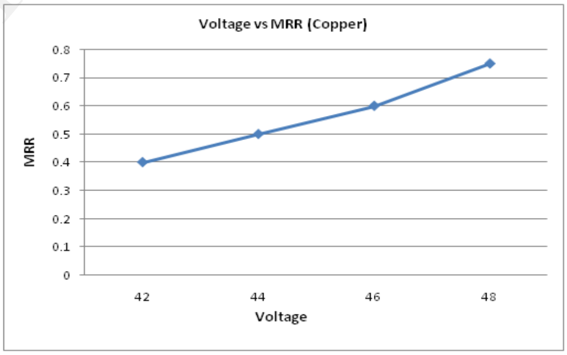

Fig No.5.4 Graph of Voltage Vs MRR for Copper Electrode

This can be explained as initially with increase in voltage, MRR increases because of higher erosion of work piece material with increase in voltage. Thereafter with further increase in voltage net deposition on work piece material from powder metallurgy tool electrode takes place. This explains the decrease in MRR with further increase in voltage.

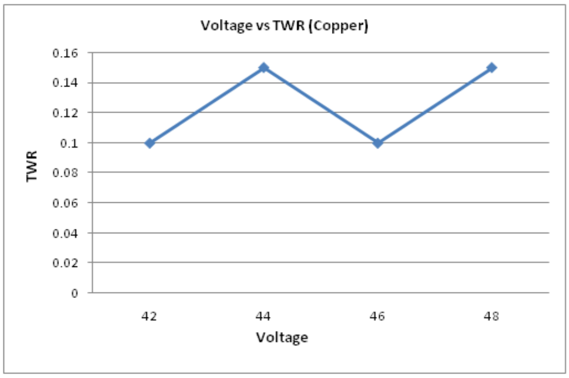

Figure No.5.5 Graph of Voltage Vs TWR for Copper Electrode

It is seen that higher the voltage more is the TWR because electric field strength increases. This results in greater wear rate of electrode with voltage increase as displayed in (Fig. 5.5).

It is observed that with an increase in voltage, Percentage WR varies slightly up to 60 Volts and then increases with voltage rise as depicted in (Fig. 5.6). These changes can be explained as increase in voltage up to 46 Volts rate of tool wear is comparable to material removal hence small variation in the curve.

After 46 Volts due to net deposition on work piece material from Copper tool electrode results in higher tool wear as compared to material removal. Therefore curve shoots upwards.

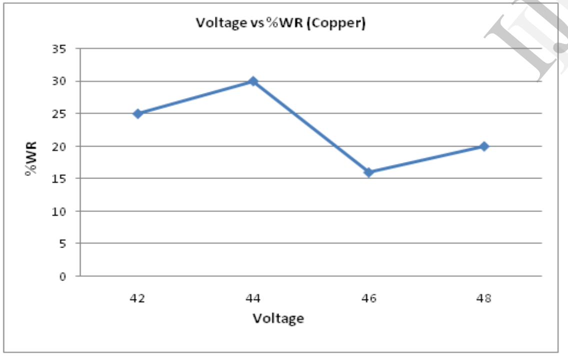

Fig No.5.6 Graph of Voltage Vs %WR for Copper Electrode

5.3 Analysis of MRR, TWR, %WR vs Current – Aluminium electrode

Amount of power used in EDM is measured in terms of its amperage and is termed as most important machining parameter in MRR. It is observed that with an increase in current, MRR improves up to 18 amperes as shown in (Fig.5.7). This can be explained as initially with increase in current MRR increases because of higher erosion of work piece material with increase in current.

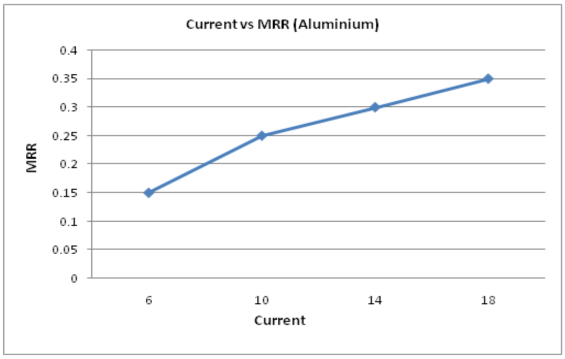

Fig 5.7 Graph of Current Vs MRR for Aluminium Electrode

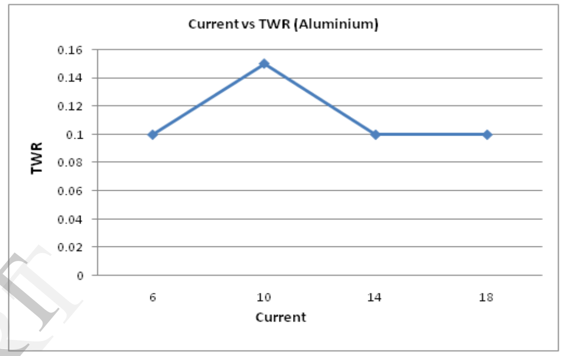

Fig. 5.8 Graph of Current Vs TWR for Aluminium Electrode

It is observed that with an increase in current, TWR increases as displayed in (Fig. 5.8) because as the current increases higher energy is available for the electrode wear. This causes more and more erosion of tool material with increase in current

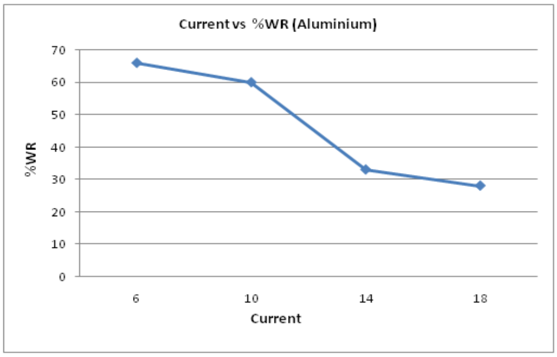

Fig. 5.9 Graph of Current Vs %WR for Aluminium Electrode

Percentage wear rate is the ratio TWR & MRR. It is observed that with an increase in current upto18ampers, Percentage WR decreases and then with further increase in current Percentage WR increases as shown in (Fig. 5.9). These variations in trend can be explained with increase in current up to 18 amperes rate of tool wear is less as compared to material removal hence downward trend of the curve. After 18 amperes due to net deposition on work piece material from powder metallurgy electrode results in higher TWR as compared to MRR. Therefore curve has an upward trend.

5.10. Analysis of MRR, TWR, %WR vs Voltage – Aluminium Electrode

MRR increases, by increasing open circuit voltage, because electric field strength increases. It is observed that with an increase in voltage, MRR improves up to 60Volts and then starts to decrease continuously as illustrated in (Fig. 5.10).

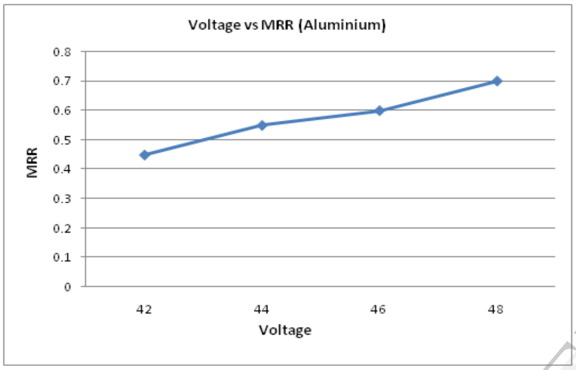

Fig. 5.10 Graph of Voltage Vs MRR for Aluminium Electrode

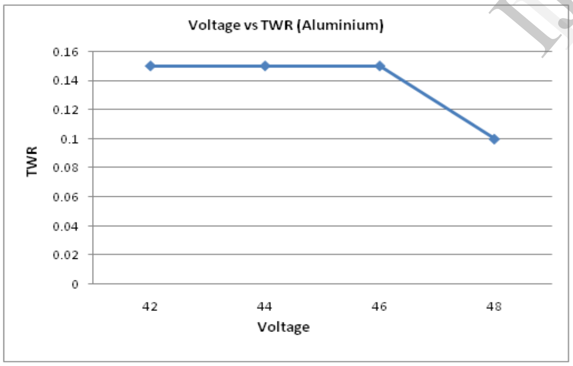

Fig.5.11 Graph of Voltage Vs TWR for Aluminium Electrode

This can be explained as initially with increase in voltage, MRR increases because of higher erosion of work piece material with increase in voltage. Thereafter with further increase in voltage net deposition on work piece material from powder metallurgy tool electrode takes place. This explains the decrease in MRR with further increase in voltage

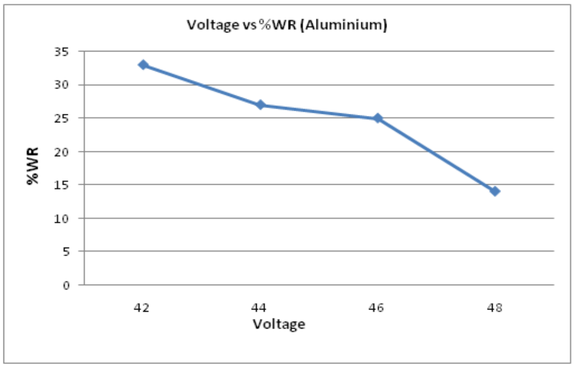

Fig.5.12 Graph of Voltage Vs %WR for Aluminium Electrode

It is seen that higher the voltage more is the TWR as shown in (Fig. 5.11) because electric field strength increases. This results in greater wear rate of electrode with voltage increase.

It is observed that with an increase in voltage, Percentage WR varies slightly up to 60 Volts and then increases with voltage rise as displayed in (Fig. 5.12). These changes can be explained as increase in voltage up to 46 Volts rate of tool wear is comparable to material removal hence small variation in the curve. After 46 Volts due to net deposition on work piece material from Aluminium tool electrode results in higher tool wear as compared to material removal. Therefore curve shoots upwards.

6. Conclusion

The present experimental work identifies the EDM process performance and the machining conditions with Copper & Aluminium tool electrode and its effect on process output parameters viz. material removal rate, tool wear rate and percentage wear rate etc. on OHNS within the selected range of parameters. Within the experimental range of the selected parameters the following conclusions are drawn from this study:

1. The maximum material removal rate is obtained at current =18A; voltage =48V.
2. The minimum tool wear rate is obtained at current =6A; voltage = 42V.
3. The minimum percentage wear rate is obtained at current =18A; voltage = 46V.
4. Material removal rate is less at low current of 6A and it increases up to value 18A and then decreases at higher value of current. Low value of MRR at low current is because of less energy available for erosion of work piece material whereas at high current in spite of higher energy MRR is less because of net material deposition of electrode material on work piece.

5. Similarly MRR is low for small voltage but rises till 48V thereafter decrease continuously. Lesser MRR at small voltage is due to low electric field strength, which results in little erosion of work piece material. At higher voltage no doubt electric field strength is large but due to material deposition on work piece MRR is less.
6. TWR rises continuously with current and voltages rise because as the current increases more energy is available for the electrode wear. Likewise as voltage rise electric field strength increases resulting in greater wear rate of electrode.
7. The percentage wear rate decreases initially up to 18ampers as tool wear is lesser compared to material removal. Thereafter due to net deposition on work piece material from electrode because tools wear is more as compared to work material. Percentages wear rate increases.

The percentage WR varies slightly up to 48 Volts and then increases with voltage rise. Initially up to 48 Volts rate of tool wear is comparable to material removal hence little variation in the curve. After 48 Volts deposition of electrode material on work surface takes place leading to higher tool wear than material removal. This result in increased Percentage wear rate.

7. Acknowledgement

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