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Research Paper

STUDY OF TOOL WEAR RATE OF DIFFERENT TOOL MATERIALS DURING ELECTRIC DISCHARGE MACHINING OF H11 STEEL AT REVERSE POLARITY

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In this paper an effort has been made to compare the usefulness of electrode made through Powder Metallurgy (PM) in comparison with conventional copper electrode during electric discharge machining. Experimental results are presented on electric discharge machining of H11 steel in standard EDM oil with copper tungsten (75% Cu and 25%W) tool electrode made through powder metallurgy technique and Copper electrode (99%Cu). An L_{18} (2^1 X 3^3) orthogonal array of Taguchi Methodology was used to identify the effect of process input parameters (viz. electrode type, peak current, voltage and duty cycle) on the output factor (viz. Tool wear rate). It was found that copper tungsten (CuW) made through powder metallurgy gives better TWR as compared to conventional electrode (Cu) and the best parametric setting for minimum TWR is with CuW powder metallurgy tool electrode, 4 ampere current, 40 volts gap voltage, 0.72 duty cycle, i.e., $A_2B_1C_1D_1$.

Keywords: Electrical Discharge Machining (EDM), Powder Metallurgy (PM), Taguchi methodology, Tool Wear Rate (TWR)

INTRODUCTION

Electrical Discharge Machining (EDM) is a well recognized machining alternative for producing geometrically complex or hard material parts that are extremely difficult to machine by conventional machining process. It has been widely used to produce dies, molds, aerospace, automobile industry and surgical components. One of the main reason for using EDM is that it is also useful for machining brittle materials, as there is virtually no contact between the tool and workpiece.

There are various phases of electrical discharges occurs during EDM. At first, the electrode move close to the workpiece, when the potential difference increases between the

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two surfaces, the dielectric fluid breaks down and ions are generated. Strong electric fluid followed by electrical discharges well produce where the distance between the two surfaces is minimum. More and more ions are generated, which will reduce the insulating property of the dielectric fluid along a narrow channel at the point where strongest electric field occurred. At this time the voltage reaches its peak, while the current is still zero. A discharge channel begins to form between the electrode and the workpiece. The voltage continues to decrease while current continues to increase. This will allow the heat to build up rapidly, causing some of the anode, cathode, and dielectric materials to vaporize. The heat and pressure, inside the channel have reached the maximum and some materials have been melted and removed. The molten metal is held in place by the pressure of the vapor. When the voltage and current approach to zero in the discharge channel and cause it to collapse, thus allowing the molten material to be expelled from the workpiece surface. The recent developments in the field of EDM have progressed due to the challenges being faced by the modern manufacturing industries. The development of new materials that is hard and difficult to machine such as tool steels, ceramics, super alloys, hastalloy, nitralloy, nemonics etc can machined easily with the help of EDM. Various tool electrodes used in EDM are copper, brass, tungsten, steel, copper-tungsten, and copper chromium alloys, etc.

Anand Kumar and Shanthil (2013) experimentally investigated the effect of dielectric medium and pulsed current on MRR, diametrical overcut, electrode wear and surface roughness while machining Monel 400. They investigated different dielectric mediums like kerosene, paraffin, EDM commercial grade oil and also kerosene + servo therm oil. Four kinds of tool electrode materials were used mainly brass and aluminium. They concluded that MRR, Surface roughness and electrode wear are increasing with process parameters for each electrode material except the prolonged pulse duration of 200 m. They also found that graphite electrode gives high MRR and brass electrode exhibit the best performance with regard surface finish. Assarzadeh and Ghoreishi (2013) optimized the process parameters in electro discharge machining of tungsten carbide cobalt composite using cylindrical copper tool electrodes in planning machining mode based on statistical techniques. The input parameters selected for the experiment are discharge current, pulse on time, duty cycle, and gap voltage. The EDM process performance is measured in terms of MRR, TWR, and average surface roughness. They concluded that MRR increases with increase in discharge current and duty cycle by providing greater amounts of discharge energy inside gap region. The TWR decreases by increase in pulse on time and low current densities while less rough surfaces attains by setting small pulse durations and relatively higher levels to discharge currents. The situation results in small sized shallow craters on the work surfaces helping to improve surface quality.

Belgassium and Abusada (2012) studied the influence of EDM parameters on surface finish of EDM material was done. The concerned EDM parameters selected are pulse current, pulse on time, pulse off time and gap voltage with surface roughness and overcut as output parameters. They concluded that pulse current is one of the influential parameters which significantly affect the surface roughness. Pulse on time and pulse current are significantly affecting the overcut. Chikalthankar *et al.* (2013) evaluated the machining of WPS DIN 1.2379/ AISI D2 tool steel with a copper as electrode by investigating parameters like MRR and SR. They found that current was the most influential in case of MRR followed by pulse on time, pulse off time and gap voltage. In case of surface roughness, the most influential factor was also current followed by pulse on time, gap voltage and pulse off time.

Daneshmand *et al.* (2012) investigated input parameters such as pulse on time, pulse off time, discharge current and gap voltage on output parameters such as tool wear rate, MRR and surface roughness. They used smart NiTi 60 alloys as work material and brass as tool electrode. They concluded that with the increase in voltage and discharge current, the tool wear, workpiece wear and surface roughness increases. Also with the increase of pulse on time, the tools wear increases up to a certain point and decreases afterwards but MRR and SR diminish. The result also shows that as the pulse off time increases, the TWR, MRR and SR diminishes. Daneshmand *et al.* (2013) investigated the impact of rotating tool and input parameters include, pulse current, pulse on time, voltage and pulse off time on output parameters such as MRR, SR and TWR in Nickel titanium alloy with copper electrode and deionized water was studied. They found that rotational tool with the increase of pulse current, pulse on time and voltage, MRR increase and when pulse off time increases, MRR diminishes. They have also found that when the rotational tool revolution is 200 rpm, MRR decreases in comparison with traditional EDM and they initiated rotational EDM with 200 rpm is lead to less MRR and better surface roughness and tool wear.

Hussain Syed and Palaniyandi (2012) experimentally investigated the effect of addition of aluminium metal powder to dielectric fluid in EDM of W300 die steel workpiece and electrolytic copper as electrode. The input parameters selected for the study are peak current, pulse on time, concentration of powder and polarity. The process performance is measured in terms of MRR, EWR, surface roughness and White Layer Thickness (WLT). They found that maximum MRR is obtained at high peak current, low EWR, low surface roughness, and minimum value of WLT is obtained for low peak current. Klocke *et al.* (2013) investigated the influence of different graphite grades on the performance of graphite electrodes in die sinking EDM. They revealed that the discharge current is the main influence on the material removal rate and the discharge duration is mainly influenced by tool wear.

Nipanikar (2012)reported the cutting of D3 steel material using EDM with copper electrode by using taguchi methodology. Peak current, gap voltage, duty cycle and pulse on time are the input parameters and MRR, EWR, and ROC are output parameters. He concluded that MRR, EWR, ROC is mainly influenced by peak current. He also found that gap voltage has less effect on EWR. Rajesh and Devanand (2012) presented a new approach to the machining problems based on the genetic algorithm and multiple regression models. The machining parameters selected for the study are current, voltage, flow rate, pulse on time, pulse off time and gap by performing machining in terms of MRR and surface roughness. They concluded that optimal conditions for maximum MRR and minimum surface roughness is obtained by Genetic Algorithm (GA) are current at 3 ampere, voltage at 78 V, gap at 0.35, flow rate at 1, pulse on as 1, and pulse off as 8 respectively.

Roth *et al.* (2012) presented a comparison of material removal rate and TWR of dry electric discharge machining with different tool electrode and workpiece materials by fixed EDM parameters. The tool electrodes used for the experiment are copper and cemented carbides and workpiece used SS304 and cemented carbides. They found that major influence on the MRR is carried by the workpiece material on the discharge behavior. Singh *et al.* (2012) investigated the effect of polarity, peak current, pulse on time, duty cycle, gap voltage and concentration of abrasive powder in dielectric fluid on surface roughness of H11 steel using copper tool electrode. They concluded that negative polarity of tool electrode is desirable for lowering surface roughness and suspension of powder particles in dielectric fluid and high peak current produce more roughness in EDM process.

Singh *et al.* (2012) studied the effect of input parameters such as polarity, peak current, pulse on time, duty cycle, gap voltage and concentration of abrasive powder in dielectric fluid on surface roughness using H13 work material. They concluded that negative polarity of tool electrode is desirable for lowering surface roughness and addition of powder particles in dielectric fluid decreases surface roughness of specimen in EDM process. Singh and Singh (2012) compared the MRR achieved using different tool materials mainly copper and brass electrode with AISI D3 as work material. The parameter selected for the study is pulse on/pulse off time. They concluded that MRR increases with increase in pulse on time for brass electrode. They also found that MRR decreases considerably with decrease in pulse on time for copper electrode.

Singh *et al.* (2012) studied the effect of different machining parameters like peak current, gap voltage, duty cycle, polarity, electrode type and retract distance during EDM of H13 tool steel. They concluded that powder metallurgy tool with reverse polarity electrode, higher values of peak current and gap voltage, average values of duty cycle and retract distances are necessary for obtaining minimum overcut. The best parameter setting for minimum overcut is found to be CuSiC (85%Cu, 15%SiC) tool electrode, 13 ampere current, 150 μsec pulse on time, 0.80 duty cycle, 60 volts gap voltage and 3 mm retract distance. Vater and Singh (2013) investigated the surface roughness process parameters optimization during WEDM process for steel. The input parameters studied are gap voltage, pulse on time, pulse off time, wire feed and flush rate using Response Surface Methodology (RSM). The work material used is EN-31 die steel with chromium coated copper alloy wire electrode. They concluded that performance of WEDM not only depends upon the combination of material of workpiece and wire electrode but also the optimal combination of the independent control process parameter.

Younis (2012) studied the effect of electrode material to avoid surface cracks by selecting two grades of high carbon high chromium alloy tool steels mainly DIN 1.2080 and DIN 1.2379. Four types of EDM electrode material selected for the studies are Dura graph 11, dura graph 15, poco graphite "EDM-C3" and copper electrodes. They concluded that by using copper electrodes upon DIN 1.2379, less micro cracks appeared on white layer surface than on DIN 1.2080. At the same time by using EDM-C3 electrode, EDM machining exhibits less thich white layer and less micro crack. Zhao *et al.* (2013) investigated the fundamental EDM characteristics of silicon carbide single crystal material with copper foil as electrode. They concluded that negative polarity is more suitable for foil EDM of SiC with higher machining speed and lower tool wear ratio under short pulse duration. They also found that thermal cracks caused by thermal stress are considered to be one main mechanism of the removal of the material in EDM process of SiC.

EXPERIMENTAL PROCEDURE

The workpiece material selected for this study was H11 chromium hot work tool steel. The chemical composition of H11 steel is shown in Table 1.

The specimen is of rectangular in shape with 65 mm length, 30 mm breadth, and 7 mm thickness. Two kinds of tool electrode materials mainly conventional copper tool electrode (99%Cu) and CuW made from powder metallurgy techniques (75%Cu and 25%CuW) was used here. Various input machining parameters with their designation and assigned values of input machining factors selected for the study are shown in Table 2 and Table 3. Spark gap which was maintained by a distance of 0.02 mm, depth of cut of 0.50 mm and dielectric fluid of standard EDM oil are the constant parameters in this study. CuW electrode made through powder metallurgy is of diameter 8.00 mm and a length of 90 mm respectively.

Here in this paper the effect of input machining parameter (viz. electrode type, peak current, gap voltage, and duty cycle) on tool wear rate is studied here. The values were noted as per the design of experiment trial conditions using taguchi method (Table 4).

A total of 18 experiments were performed (as per Table 5) and at the end of each experiment the tool electrode was taken out

Table 1: Chemical Composition of H11 (wt%)

Carbon (C)	Manganese (Mn)	Silicon (Si)	Chromium (Cr)	Nickel (Ni)	Molybdenum (Mo)	Vanadium (V)	Copper (Cu)	Sulphur (S)
0.35	0.20-0.50	0.80-1.20	4.75-5.50	0.3	1.10-1.60	0.03-0.60	0.25	0.03

Table 2: Input Machining Parameters with Their Designation

Machining Parameter	Electrode Type	Peak Current (Amp)	Gap Voltage (Volt)	Duty Cycle
Symbol	A	B	C	D

Table 3: Selected Input Machining Parameters

Variable	Set-Up	Units
Work piece	H11 Chromium hot work tool steel	–
Work piece material size	65 x 30 x 7	mm
Tool electrode material	Conventional copper and powder metallurgy copper tungsten	–
Tool electrode diameter	8	mm
Polarity	Negative	–
Gap voltage	40-60	V
Peak current	4-14	A
Pulse on time	150	μsec
Duty cycle	0.72-0.92	–
Dielectric fluid	Standard EDM oil	–
Flushing	Jet Flushing	–
Flushing pressure	3-5	Kg/cm²

Table 4: Assigned Values of Input Machining Parameters at Different Levels and Their Designation

Factor Designation	Machining Parameter (Units)	Levels and Corresponding Values of Machining Parameter		
		Level 1	Level 2	Level 3
A	Electrode Type	Conventional Copper	Powder Metallurgy Electrode (CuW)	–
B	Peak Current (A)	4	9	14
C	Gap Voltage (V)	40	50	60
D	Duty Cycle	0.72	0.82	0.92

Table 5: Design Matrix of L_{18} (2^1 x 3^3) Orthogonal Array

Exp. No.	Electrode Type A	Peak Current (Amp) B	Gap Voltage (Volt) C	Duty Cycle D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2

Table 5 (Cont.)

Exp. No.	Electrode Type A	Peak Current (Amp) B	Gap Voltage (Volt) C	Duty Cycle D
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

to find out the final weight of the electrode. So that corresponding TWR can be calculated.

The tool wear rate can be calculated by using the relation shown in below.

$$TWR = \frac{Wei - Wef}{t} \text{ in gm/min}$$

where,

Wei = Initial weight of tool electrode.

Wef = Final weight of tool electrode.

RESULTS AND DISCUSSION

The experimental results for TWR are tabulated in Table 6.

For TWR the requirement is to minimize it so the criteria selected using the software is

Table 6: Experimental Results for TWR

Exp. No.	Weight of Electrode Before Machining (gm)	Weight of Electrode After Machining (gm)	Weight of Electrode Before Machining-Weight of Electrode After Machining (gm)	Machining Time (Min)	TWR (gm/min)
1	115.332	115.309	0.023	90.27	0.000254791
2	115.309	115.277	0.032	61.12	0.000523560
3	115.277	115.257	0.020	44.44	0.000450045
4	115.257	115.234	0.023	27.09	0.000849022
5	115.234	115.211	0.023	19.18	0.001199166
6	115.211	115.177	0.034	19.48	0.001745380
7	115.177	115.169	0.008	31.03	0.000257815
8	115.169	115.148	0.021	36.52	0.000575027
9	115.148	115.130	0.018	57.48	0.000313152
10	145.086	145.064	0.022	109.2	0.000201465
11	145.064	145.031	0.033	85.03	0.000388098
12	145.031	144.991	0.042	120	0.000333333
13	144.991	144.966	0.025	60.02	0.000416528
14	144.966	144.894	0.072	43.3	0.001662818
15	144.894	144.879	0.015	51.25	0.000292683
16	144.879	144.826	0.053	46.1	0.001149675
17	144.826	144.801	0.025	45.52	0.000549221
18	144.801	144.768	0.033	54.02	0.000610885

Table 7: Analysis of Variance for Means of SN Ratio for TWR (Smaller is Better)

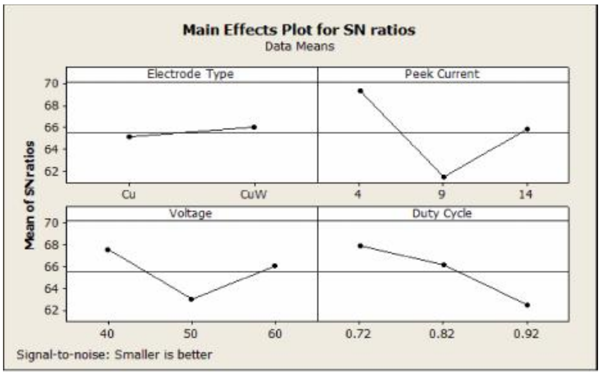
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Electrode type	1	3.305	3.305	3.305	0.28	0.624
Peak current	2	186.658	186.658	93.329	7.93	0.041
Voltage	2	65.975	83.805	41.903	3.56	0.129
Duty cycle	2	90.771	77.873	38.937	3.31	0.142
Electrode type*Peak current	2	121.077	121.077	60.539	5.15	0.078
Electrode type*Voltage	2	12.848	12.848	6.424	0.55	0.617
Electrode type*Duty cycle	2	20.182	20.182	10.091	0.86	0.490
Residual error	4	47.055	47.055	11.764		
Total	**17**	**547.87**				

"smaller is better". An ANOVA Table 7 is used to summarize the experimental results. It clearly indicates from Table 8 that the peak current and duty cycle are the most influencing factor for TWR and voltage and electrode type are relatively less influencing factor. Interaction of electrode type and peak current is also influencing TWR.

Table 8: Response Table for SN Ratio for TWR (Smaller is Better)

Level	Electrode Type	Peak Current (Amp)	Voltage (Volt)	Duty Cycle
1	65.12	69.35	67.56	67.91
2	65.98	61.48	62.98	66.21
3		65.82	66.11	62.53
Delta	0.86	7.87	4.59	5.38
Rank	4	1	3	2

Figure 1: Main Effects Plots for SN Ratios (TWR)



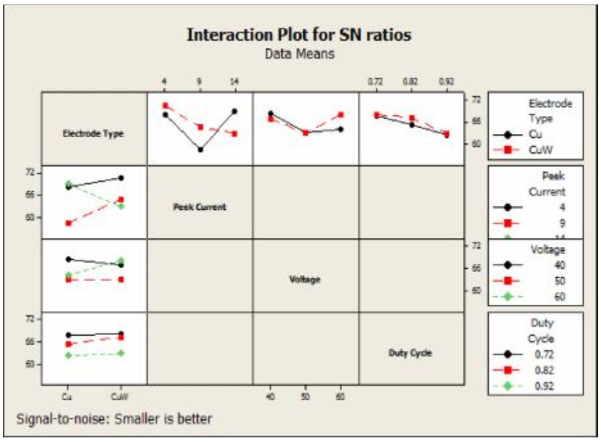
As per Figure 1 main effect plot for SN ratios, TWR is minimum at the 2nd level of electrode type, 1st level of peak current, 1st level of voltage and 1st level of duty cycle. From the main effects plots for SN ratios it is observed that these level of the parameters are best level for minimum TWR as sown in Table 9.

Table 9: Best Level of Parameters at Minimum TWR

Factor	A	B	C	D
Level	2	1	1	1

Since TWR is an important factor because it affects dimensional accuracy and the shape produced, it is related to the melting point of the electrode tool materials. TWR is observed more when conducting experiment with powder metallurgy copper tungsten tool electrode with composition high copper and low carbon by weight. Tool wear rate increases with increase in peak current due to the reason more powerful sparking with higher energy occurs which produces more heat at both tool and workpiece material surfaces at higher currents. TWR increases with increase in gap

Figure 2: Interaction Plot for SN Ratios (TWR)



voltage. It is probably due to reason that at higher values of gap voltage, the more heating of work material is due to the reason that carbon layer deposited on the tool surface due to deionization process wash away at higher pressure and hence erosion rate of tool electrode increases. TWR increases with the increase of duty cycle. This is due to the expansion of plasma channel at high pulse on time occurs. Due to this the energy density of discharging spots decreases which are not enough to melt the tool material and hence rate of tool wears lowers down.

The interaction plot of TWR at different current, electrode, voltage and duty cycle is sown in Figure 2.

From the interaction plot the following observations are drawn.

- At low current from 4 Amp to 9 Amp there is little effect on TWR after that TWR increases with the increase of current value for conventional copper tool electrode.
- With powder metallurgy copper tungsten (75%Cu and 25%W) tool electrode, it is observed that tool wear rate decreases continuously with increase in peak current.
- TWR decreases with the increase in voltage up to 50 volt and after that TWR increases with the increase in voltage for conventional copper tool electrode.
- For powder metallurgy copper tungsten tool electrode it is observed that TWR decreases with the increase in voltage up to 50 volt and after that TWR increases continuously up to 60 volt.
- TWR continuously decreases with the increase in duty cycle for conventional copper tool electrode.
- For powder metallurgy copper tungsten tool electrode, TWR decreases continuously with the increase in duty cycle up to 0.92.

CONCLUSION

Following conclusions can be drawn from the analysis of the results.

- From the experimental results it was found that powder metallurgy tool electrode (CuW) gives better TWR as compared to conventional electrode.
- TWR increases with the increase in peak current, gap voltage and duty cycle.
- Best parametric setting for minimum TWR is with CuW powder metallurgy tool electrode, 4 ampere current, 40 volts gap voltage, 0.72 duty cycle. That is $A_2B_1C_1D_1$.

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