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Research Paper

TO STUDY THE EFFECT OF COPPER TUNGSTEN AND CRYOGENIC COPPER TUNGSTEN ELECTRODE ON MATERIAL REMOVAL RATE DURING ELECTRICAL DISCHARGE MACHINING OF H11 TOOL STEEL AT STRAIGHT POLARITY

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EDM is used for machining of parts of aerospace, automobile, nuclear and surgical industry. In this research paper an attempt has been made to study the effect of cryogenic treatment on powder metallurgy copper tungsten electrode at different machining parameters, i.e., peak current, gap voltage, duty cycle, polarity and electrode type during EDM of H11 tool steel. H11 is basically 5% chromium and 1.5% molybdenum hot work tool steel. The presence of molybdenum in H11 increases its hardness and is usually known as difficult to machine by conventional machining process. This research work was undertaken to study the machining performance of EDM with different electrodes, i.e., PM copper tungsten (CuW) (75% cu and 25% tungsten) and cryogenically treated PM copper tungsten (CuW) tool electrode on H11 hot work tool steel. A L18 Taguchi's standard orthogonal array is used for experimental design by varying different input machining parameters such as current, gap voltage, duty cycle, polarity, retract distance and their effect on material removal rate (MRR). It was found that material removal rate is maximum with cryogenically treated powder metallurgy copper tungsten (CuW) tool electrode with peak current (14A) at gap voltage (60V) and duty cycle (0.72) in +VE polarity.

Keywords: Electrical Discharge Machining (EDM), Material Removal Rate (MRR), Powder Metallurgy (PM), Taguchi method, Cryogenic Copper tungsten (CuW)

INTRODUCTION

Electrical Discharge Machining (EDM) is the process of machining electrically conductive materials by using precisely controlled sparks that occur between an electrode and a work piece in the presence of a dielectric fluid. The electrode may be considered the cutting tool. Sparking takes place from the electrode

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surface to the work piece. In EDM, the electrode does not contact the work piece. The electrode must always be spaced away from the work piece by the distance required for sparking, known as the sparking gap. Should the electrode contact the work piece, sparking will cease and no material will be removed. EDM is a thermal process; material is removed by heat.

Cryogenics Process

Cryogenic process is a onetime permanent process. It is a process that uses cryogenic temperatures to modify materials to enhance their performance. Cryogenic process factors have their own effect on the mechanical properties of material. It makes the crystal more perfect, stronger, relieves residual stresses, and improves electrical properties. Cryogenic Processing involves the slow reduction in temperature of the material to at least –300 °F (–185 °C) to cause beneficial changes in the material properties and holding the material at that temperature for some period of hours followed by a slow increase of temperature back to room temperature. The hard materials after Cryogenic processing makes changes to the crystal structure of materials. It is believed that cryogenically processing makes the crystal more perfect and therefore stronger. Cryogenic processing will not itself harden metal like quenching and tempering. It is not a substitute for heat-treating. It is an addition to heat-treating. Most alloys will not show much of a change in hardness due to cryogenically processing. Cryogenic Processing is not a coating. It affects the entire volume of the material.

PROBLEM FORMULATION

Most materials are so hard and it is very difficult to machined hard alloys by conventional machining processes. Instead of conventional machining, EDM process or non-traditional machining processes is a best machining process for the machining of hard alloys. However, not much work has been reported in the investigation of effect of Cryogenic Treated electrode while used as a tool in EDM. In this research work, efforts have been made to study the effect of Deep Cryogenic treatment on the performance of EDM machining characteristics using Taguchi design approach to analyze the Material Removal Rate (MRR).

LITERATURE SURVEY

Tsai *et al.* (2003) proposed a new method of blending the copper powders contained resin with chromium powders to form tool electrodes. The results showed that using such electrodes facilitated the formation of a modified surface layer on the work piece after EDM, with remarkable corrosion resistant properties. Furthermore a higher MRR is obtained as compared to Cu metal electrodes, the recast layer was thinner and fewer cracks were present on the machined surface.

Simao *et al.* (2003) reviewed published work on deliberate surface alloying of various work piece materials using EDM and have given the details of operations involving PM tool electrodes and use of powders suspended in the dielectric fluid, typically aluminium, nickel, titanium, etc.

Schumacher (2004) discussed the electric discharge machining process in detail he stipulated ignition of electrical discharges by the evaporation of particle bridges in the gap through excessive current. The follow-up spot of a discharge is conditioned by the remaining particles, removed from the electrodes, as well as gas bubbles from earlier discharges. The material removal reaction is grouped in an evaporation phase at start of ignition and later in the ejection of fused material by instantaneous boiling at the discharge spots. The gap width derives from the gap contamination average, depending from process settings.

Kuriakose *et al.* (2005) presented the methodology and data from an experiment that measures the normal force and friction force directly in an altered machining setup. The procedure simulates the pure frictional behavior of the tool-chip interface in cryogenically cutting. The results show that LN2 cooled condition has a significantly lower coefficient of friction than dry conditions in all cases. The data also shows that the friction is lower for Ti-6Al-4V but mixed results obtained for mild steel AISI 1018 when LN2 is applied properly as in the experiment setup as compared to traditional emulsion flooding. Based on the unique pattern of the friction behaviour in the sliding tests, possible lubrication mechanisms using liquid nitrogen are proposed.

Duowon *et al.* (2006) suggested that in EDM operation the work piece as well as the tool (electrode) experience an intense local heating in the vicinity of plasma channel. The high power density would result in the erosion of a part of material both from the work piece and the electrode by the local melting and heating. When high material removal rate is desirable with good surface quality, erosion of electrode is unwanted. So a proper selection of tool materials and choice of parameters like pulse power, width and polarity were investigated.

Khanra *et al.* (2007) developed ZrB2-Cu composite by adding different amount of Cu and tested as a tool material for machining of mild steel. The result shows that ZrB2-40 wt% Cu composite has more MRR, with less tool removed rate than commonly used Cu tool. But diametric over cut and average surface roughness are found to be lesser in case of Cu tool.

Lajis *et al.* (2009) reported that effect of tungsten carbide ceramic on graphite electrode by analyzing the machining characteristics. The input parameters selected are peak current, voltage, pulse duration and interval time. The output parameters include Material removal rate, Electrode wear rate, and surface roughness. The taguchi method is used to formulate the experimental layout and reveals that peak current significantly affects the electrode wear rate and surface roughness, while pulse duration mainly affects the material removal rate.

Patel *et al.* (2010) experimentally investigated parameters affecting surface roughness along with structural analysis of surfaces with respect to material removal parameters. The conducted their experiment on mild steel with copper, brass and graphite as tool electrodes with kerosene oil as dielectric fluid. They concluded that MRR increases with increase in discharge current for all three electrodes, but in case of brass and copper it decreases after some limit, due to pulse energy increases as the current increases. They used Scanning Electron Microscope (SEM) and optical microscope to understand the mode of Heat Affected Zone (HAZ). They also observed that molten mass has been removed from surface as ligaments and sheets but in some cases it is removed as chunks, which being in molten state stuck to surface.

Sharma *et al.* (2010) studied the effect of aluminium powder on machining hast alloy using EDM with reverse polarity by evaluating MRR, TWR, %wear rate, SR. The input parameters selected for the study are concentration and grain size of aluminium powder. They found that with the increase in the concentration of aluminium powder, surface roughness and %wear rate decreases but TWR and MRR increases.

Beri *et al.* (2011) experimentally investigated AISI D2 steel in kerosene with CuW (25% Cu and 75% W) powder metallurgy electrode. An L18 orthogonal array was used to identify the best process parameters (Viz. electrode material, duty cycle, flushing pressure, and current, etc.) for MRR, SR, and surface hardness. Grey relational analysis was used to solve the EDM process with multiple performance characteristics which was obtained through grey relation grade. They concluded that EDM process performance can be improved efficiently through this approach and they also concluded that copper tungsten PM electrode gives better multi objective performance than conventional copper electrode.

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) 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.* (2013) studied the influence of operating parameters like pulse-on-time and pulse-off-time for responses such as Metal Removal Rate (MRR) and Tool Wear Ratio (TWR) on the EDM using steel as work piece and cryogenic and non-cryogenic electrode of copper material. The cryogenic treatment is used for increasing the material removal rate and lowering the tool wear rate. It was found that with increase in pulse on time tool wear rate is decreased in both electrode cryogenic treated and non-cryogenic copper electrode. Tool wear rate is increased with increase in pulse off time. Material removal rate is decreased with increased in pulse on time from 50 μs to 100 μs and Material removal rate is increased with increased in pulse off time from 15 μs to 20 μs.

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.

EXPERIMENTAL SET-UP

The main objectives of the research work are:

1. To find the effects of deep cryogenic treatment on Powder metallurgy copper tungsten electrode during EDM of H11 tool steel.
2. To find the effects of cryogenic copper tungsten tool on MRR during EDM of H11 tool steel.
3. Analysis of input machining parameters viz. peak current, gap voltage, duty cycle, polarity and electrode type during EDM of H-11 tool steel using Taguchi experimental design technique.

Machine Used

Electric Discharge Machine; model SMART ZNC of Electronica India Pvt. Ltd., Pune with servo head was used in this experiment. In this machine, the Z axis is servo controlled and can be programmed to follow an NC code which is fed through the control panel. The gap voltage between the tool and work piece electrodes is responsible for servo control feedback. During machining, a constant gap distance will maintain and tool is fed in to the Work piece. As machining takes place, the tool is fed into the work piece to maintain a constant gap voltage, and this determines the gap distance. The X and Y axes are manually controlled. Through an NC code, machining can be programmed to occur up to a fixed depth of cut. Alternately, sparks can be stopped manually after the desired time interval of machining has elapsed.

Work Piece Material

For the present study H11 hot work tool steel is selected as work piece material. Work piece of size 55 x 25 x 5 mm is used here. H11 is basically 5% chromium hot work steel. The 1.5% molybdenum imparts very high hardenability to this grade and makes difficult to machine by traditional machining methods. It has good resistance to softening at elevated temperatures, but its outstanding characteristics are high toughness. A slight modification of this grade has been widely used for aircraft and structural applications requiring good ductility and notch strength at high strength levels. The chemical composition of H11 is shown in Table 1.

Electrode Material

The electrode material selected for the present investigation is copper tungsten (75% Cu and 25% W) electrode) and cryogenically treated Copper tungsten (75% Cu and 25% W) electrodes. CuW electrodes are made through powder metallurgy technique by mixing weight of copper and tungsten in blenders. The mixture is then compacted in a die to form green compact. This compact is sintered in a sintering furnace to the temperature of

1600 °C and sintering time is kept between 3 to 6 hours and cryogenically treated copper tungsten was made by process which takes place by slow reduction in temperature of the material to at least –300 °F (–185 °C) and holding the material at that temperature for some period of hours followed by a slow increase of temperature back to room temperature. It makes the electrode more perfect, stronger, relieves residual stresses, and improves electrical properties. The change brought about by cryogenically processing is permanent.

Design of Experiment

Design of experiment is the primary step before starting the experimental work. Design of Experiments (DOE) is used to study the effect of multiple variable simultaneously, which is a powerful statistical technique introduced by Fisher in England in 1920's. Table 2 shows the selected input machining parameters with their designation and values assigned to them at different levels.

Taguchi Experimental Design and Analysis

Taguchi method simplifies and standardizes the fractional design by introducing Orthogonal Array (OA) for constructing or laying out the design of experiments. It also suggests a standard method for the analysis of results. A factorial experiment with 4 parameters each at three levels would require ($3^4 = 81$) test runs whereas Taguchi L18 orthogonal array would require only 18 trial runs for providing same information. Design Matrix using the L18 orthogonal array are presented in Table 3.

Set-up And Experimental Procedure

A total of 18 experiments were performed (Table 4) and at end of each experiment electrode and work piece was taken out and was weighed to find out the final weight after cut. The electrode was machined again to remove distortions and obtain a flat face and a uniform diameter for the next cut. It was weighed to find out the initial mass for the next cut.

Table 1: Chemical Composition of H11 Material

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: Assigned Values of Input Machining Parameters at Different Levels and their Designation

FACTOR DESIGNATION	MACHINING PARAMETERS (UNITS)	LEVEL AND CORRESPONDING VALUES OF MACHINING PARAMETERS		
		LEVEL 1	LEVEL 2	LEVEL 3
A	ELECTRODE TYPE	CuW ELECTRODE	CRYOGENICALLY TREATED CuW ELECTRODE	....
B	PEAK CURRENT A	4	9	14
C	GAP VOLTAGE V	40	50	60
D	DUTY CYCLE	0.72	0.82	0.92

Note: Four parameters used in this research, i.e., electrode type (copper tungsten and cryogenic copper tungsten), peak current (4, 9 and 14), gap voltage (40, 50 and 60 volt) and last but not least duty cycle (0.72, 0.82 and 0.92).

Table 3: Design Matrix of L18 (21 x 33)

Exp. No	Electrode Type	Peak Current	Voltage	Duty Cycle
1	Z	4	40	0.72
2	Z	4	50	0.82
3	Z	4	60	0.92
4	Z	9	40	0.72
5	Z	9	50	0.82
6	Z	9	60	0.92
7	Z	14	40	0.82
8	Z	14	50	0.92
9	Z	14	60	0.72
10	X	4	40	0.92
11	X	4	50	0.72
12	X	4	60	0.82
13	X	9	40	0.82
14	X	9	50	0.92
15	X	9	60	0.72
16	X	14	40	0.92
17	X	14	50	0.72
18	X	14	60	0.82

Note: Z stands for copper tungsten electrode and X Stands for cryogenically treated copper tungsten electrode. A L18 (33 x 21) Taguchi's standard orthogonal array is selected for the present study. This orthogonal array has 4 columns and 18 rows. One machining parameter is assigned to each column. Total 18 rows give the parametric combination for each set of experiment.

The quantity of material removed rate in each cut was known from the difference in the weight of the work piece before and after machining. The Material Removal Rate (MRR) is calculated as:

$$MRR = (Ww1 - Ww2)/T \text{ gm/sec}$$

where,

Ww1 = initial weight of work piece

Ww2 = final weight of work piece

T = Machining time

Taguchi method Assigned values of input machining parameters at different levels and their designation.

Table 4: Experimental Results for MRR

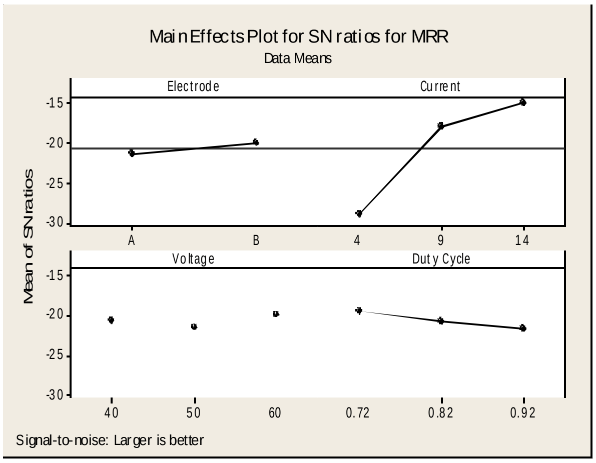
Exp No.	Weight of workpiece before	Weight of workpiece after	Weight of workpiece before	Machining time (min)	Material removal rate (gm/min)
1	52.024	51.795	0.229	5.47	0.04186472
2	51.795	51.494	0.301	10.24	0.02939453
3	51.494	51.166	0.328	12.14	0.02701812
4	51.166	50.941	0.225	2.14	0.10514019
5	50.749	50.528	0.221	2.15	0.1027907
6	50.528	50.301	0.227	1.59	0.1427673
7	49.351	48.982	0.369	2.15	0.17162791
8	48.982	48.733	0.249	2.49	0.08840446
9	48.733	48.546	0.187	0.58	0.32241379
10	48.546	48.324	0.222	4.35	0.05103448
11	48.324	48.078	0.246	6.29	0.0391097
12	48.078	47.854	0.224	7.10	0.0315493
13	47.854	47.646	0.208	1.46	0.14246575
14	47.646	47.330	0.316	2.10	0.15047619
15	47.330	47.023	0.307	2.58	0.11899225
16	47.023	46.779	0.244	2.09	0.11674641
17	46.779	46.543	0.236	1.02	0.23137255
18	46.543	46.293	0.25	1.04	0.24038462

Note: Various readings of weight of work piece before and after machining along with the machining time and material removal rate.

RESULTS AND DISCUSSION

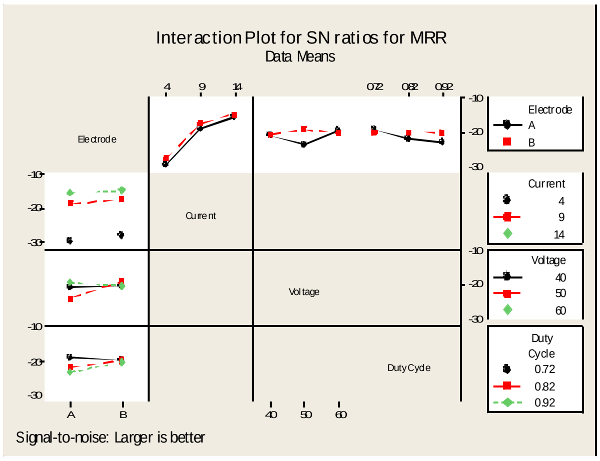
The results obtained after experimentation on Electrical Discharge Machining of H-11 Die Tool Steel with copper tungsten and cryogenic copper tungsten (75% Cu and 25% W) and the analysis and discussion on the Material Removal Rate (MRR).The experimental plans for EDM process were based on Taguchi method and for analyzing the data; analysis of variance (ANOVA) is performed using MINITAB software. In the present work the result shows that the effect of Material Removal Rate is more when conducting the experiments at positive polarity with cryogenic copper tungsten tool electrode. Small mass electrons have more velocity; they strike the work piece with heavy momentum and with high energy therefore more energy at work piece erodes more material from work piece. Material Removal Rate with Powder Metallurgy simple CuW is lower than cryogenic copper tungsten electrode. MRR increases with increase in peak current because of higher erosion of work piece material this is mainly due to more spark between tool and the work

Figure 1: Main Effects Plot for SN Ratios (MRR)



Note: MRR is maximum at the 2nd level of electrode type, 3rd level of peak current, 3rd level of gap voltage and 1st level of duty cycle; As per Table 7, A2, B3, C3 and D1 are the best parameters to give maximum MRR.

Figure 2: Interaction Plot for SN Ratios



Note: Figure 2 represents the variations in MMR with respect to the different levels of parameters, i.e., peak current, gap voltage, duty cycle and electrode type.

piece hence temperature between tool and work piece will increases which will automatically increases the MRR. It is observed that increase in duty cycle leads to decrease in MRR. In case of gap voltage, MRR increases when the gap voltage increased.

The interaction plot of MRR for different electrode, peak current, voltage and duty cycle is shown in Figure 2. Following observations can be drawn from the interaction plot.

1. It was found that A2, B3, C3 and D1 are the best treatment combinations to give maximum MRR.
2. MRR increases with the increase in peak current for both electrode, but MRR is more with the cryogenic copper tungsten (CuW) electrode as compared with the copper tungsten electrode.
3. MRR decreases with the increase in gap voltage from 40 to 50 volt and when gap voltage increases from 50 to 60 volt material removal rate increases for copper tungsten electrode and in the case of cryogenic copper tungsten electrode MRR increases with increase in gap voltage from 40 to 50 volt and further decrease with increases in gap voltage from 50 to 60 volt.
4. MRR decreases when duty cycle increases from 0.72 to 0.82 and MRR also decreases with further increase in duty cycle from 0.82 to 0.92 for copper tungsten electrode.
5. MRR remains same when duty cycle increase from 0.72 to 0.82 and when duty cycle increases from 0.82 to 0.92 MRR decreases for cryogenic copper tungsten electrode. These results confirm the results that achieved from Anova Table 6.

Table 5: Analysis of Variance for SN Ratios for MRR (Larger is Better)

SOURCE	DF	Seq SS	Adj SS	Adj MS	F	P
Electrode	1	8.506	8.506	8.506	0.83	0.413
Current	2	644.966	644.966	322.483	31.59	0.004
Voltage	2	7.982	7.982	5.948	0.58	0.6
Duty Cycle	2	16.609	16.609	11.162	1.09	0.418
Electrode*Current	2	0.809	0.809	0.405	0.04	0.962
Electrode*Voltage	2	32.031	32.031	16.015	1.57	0.314
Electrode*Duty Cycle	2	14.892	14.892	7.446	0.73	0.537
Residual Error	4	40.838	40.838	10.210		
Total	17	766.634				

Note: Analysis of variance for SN Ratios for MRR (larger is better). Taguchi method is used to analyze the result of MRR for larger is better criteria.

Table 6: Response Table for SN Ratio for MRR (Larger is Better)

Level	Electrode	Current	Voltage	Duty Cycle
1	-21.33	-28.93	-20.64	-19.39
2	-19.96	-18.02	-21.46	-20.84
3		-14.99	-19.83	-21.72
DELTA	1.37	13.94	1.63	2.33
RANK	4	1	3	2

Note: Response for SN Ratios for MRR (Larger is better) are shown in the Table 6 from the delta values and the rank assigned to various input parameters and by considering the case. Which is clearly indicates that the, electrode type and gap voltage are relatively less influencing factors to MRR. Peak current and duty cycle are the most influencing factors for MRR.

Table 7: Best Level of Parameters at Maximum MRR

FACTOR	A	B	C	D
LEVEL	2	3	3	1

CONCLUSION

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

1. Cryogenic copper tungsten electrode is feasible for the EDM of H-11 die tool steel at straight polarity.
2. Material removal Rate increases with the increase in current due to predominant increase in spark energy.
3. Positive polarity with 14 amp current, gap voltage of 60V and duty cycle of 0.72 gives the best results for MRR, i.e., A2, B3, C3, D1.
4. Material Removal rate are critical parameter in EDM. Since cryogenic treated tool has a significant positive effect on this parameter, it can be recommended that cryogenically treated electrode gives best result in material removal rate.

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