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Research Paper

STUDY OF MATERIAL REMOVAL RATE OF H11 DIE TOOL STEEL DURING ELECTRIC DISCHARGE MACHINING AT NORMAL POLARITY

Sumesh Kapila[1]* and Dinesh Kumar[2]

*Corresponding Author: **Sumesh Kapila** ✉ sumesh.kapila@gmail.com

Non-Conventional methods are widely used due to their time saving process with superior quality. In non-conventional machining process we use thermal energy provided by a heat source, to melts and (or) vaporizes the volume of the material to be removed. Among thermal removal methods, Electric discharge machining is most widely used method for making tools such as Die steel, tool steel which are difficult to machine by simple methods. It was found that considerable research has been done on various aspects of electrical discharge machining of low carbon steels, carbides and a few die steels such as AISI D2, H13, haste alloy etc. steel, with different types of electrodes such as ZrB2-Cu, Cu, CuW etc. but sufficient data has not available on H-11 steel. H-11 is a Die tool steel. H-11 offers high corrosion resistance, wear strength and high hardness. It is widely used in extrusion tools, forging dies, stamping dies, etc. Hence there is a need to investigate the machining of this material with copper and copper tungsten (CuW) electrodes (made through powder metallurgy technique). A L_{18} Taguchi's standard orthogonal array is used for experimental design by varying different input machining parameters such as discharge 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 conventional copper electrode with peek current (14A) at voltage (40V) and duty cycle (0.92) in Positive polarity.

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

INTRODUCTION

With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other manufacturing industries due to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed.

[1] Department of Mechanical Engineering, SSCET, Badhani, Pathankot, Punjab, India.

[2] H.O.D. Department of Mechanical Engineering, SSCET, Badhani, Pathankot, Punjab, India.

New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. As we know there are many conventional machining or material removal processes. Non-traditional machining methods have grown due to need to machine exotic materials. The machining processes are non-traditional in the sense that they do not employ traditional tools for metal removal and instead they directly use other forms of energy. The problems of high complexity in shape, size and higher demand for product accuracy and surface finish can be solved through non-traditional methods. In non-conventional machining process we use thermal energy provided by a heat source, to melts and/or vaporizes the volume of the material to be removed. Among thermal removal methods, electrical discharge machining or EDM is the oldest and most widely used.

The history of EDM starts since 1970 by English Physicist Joseph Priestley who studied the erosive effect of electrical discharges. But EDM was not taken into advantage as the EDM machine was very uncertain and enigma with failures. During 1943 two Russian scientists Dr. B.R. Lazarenko and Dr. N.I. Lazarenko scientists learned how the erosive effects of the electrical discharges technique could be used for machining purposes in controlled manners. In their efforts to exploit the destructive effects of an electrical discharge, they developed a controlled process for machining of metals. Their initial process used a spark machining process, named after the succession of sparks (electrical discharges) that took place between two electrical conductors immersed in a dielectric fluid. The discharge generator effect used by this machine, known as the Lazarenko Circuit, was used for many years in the construction of generators for electrical discharge. New researchers entered the field and contributed many fundamental characteristics of the machining method we know today. In 1952, the manufacturer Charmilles created the first machine using the spark machining process and was presented for the first time at the European Machine Tool Exhibition in 1955. In 1969, Agie launched the world's first numerically controlled wire-cut EDM machine. Developed in the mid-1970s, wire EDM began to be a viable technique that helped shape the metal working industry we see today. Seibu developed the first CNC wire EDM machine in 1972 and the first system was manufactured in Japan. In the mid-1980s the EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over traditional machining processes. EDM is a thermo-electric non-traditional machining process. Material is removed from the workpiece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Workpiece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the workpiece surface is smallest. After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the workpiece surface. In this way several sparks occur at various locations over the entire surface of the workpiece corresponding to the workpiece-tool gap. Because of the material removal due to sparks, after some time a uniform gap distance is formed throughout the gap between the tool and the workpiece. However if the tool is fed continuously towards the workpiece then the process is repeated and more material is removed. The tool is fed until the required depth of cut is achieved. Finally, a cavity corresponding to replica of the tool shape is formed on the workpiece. The tool and the workpiece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the workpiece is generally provided for maintaining a constant gap distance between the tool and the workpiece during machining. This is performed by either a servo motor control or stepper motor control of the tool holder. As material gets removed from the workpiece, the tool is moved downward towards the workpiece to maintain a constant inter-electrode gap. The tool and the workpiece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter-electrode gap. Typically in oil die-sinking EDM, pulsed DC power supply is used where the tool is connected to the negative terminal and the workpiece is connected to the positive terminal. The pulse frequency may vary from a few kHz to several MHz. Material removal rates of up to 300 mm^3/min can be achieved during EDM. The surface finish (Ra value) can be as high as 50 µm during rough machining and even less than 1 µm during finish machining.

LITERATURE SURVEY

S L Chen *et al*., (1999), investigated that the material removal rate is greater and the relative electrode wear ratio is lower, when machining in distilled water rather than in kerosene.

Jose Marafona and Catherine Wykes *et al*., (2000), has carried out experiment and development of a two-stage EDM machining process where different EDM settings are used for the two stages of the process giving a significantly improved material removal rate for a given tool wear ratio.

S H Lee and X P LI *et al*., (2001), analyzed the influence of operating parameters of edm of tungsten carbide on the machining characteristics. The effectiveness of edm process with tungsten carbide is evaluated in terms of the material removal rate, the relative wear ratio and the surface finish quality of the workpiece is produced. It is observed that copper tungsten is most suitable for use as the tool electrode in edm of tungsten carbide.

K H Ho and S T Newman *et al*., (2003), reported on the EDM research relating to improving performance measures, optimizing the process variables, monitoring and control the sparking process, simplifying the electrode design and manufacture.

Naveen Beri and S Maheshwari *et al.*, (2008), analyzed to correlate the usefulness of electrodes made through powder metallurgy (PM) in comparison with conventional copper electrode during electric discharge machining. 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. An L18 orthogonal array of Taguchi methodology was used to identify the effect of process input factors (viz. current, duty cycle and flushing pressure) on the output factors MRR and SR. It was found that CuW electrode gives high surface finish whereas the Cu electrode is better for higher material removal rate.

Saurabh Sharma and Anil Kumar *et al.*, (2010). Analyzed the effect of aluminum powder on the machining performance of conventional EDM with reverse polarity. The machining performance is evaluated in terms of material removal rate, tool wear rate, percentage wear rate, surface roughness. It is found experimentally that powder characteristics significantly affect machining characteristics.

Vijay Kumar and Naveen Beri *et al.*, (2010). Analyzed the process performance of electrical discharge machining with powder metallurgy tool electrode during the machining of haste alloy using positive Polarity. It indicates that, the maximum material removal rate is at the average value of current and above average value of voltage within selected range of process input parameters, the minimum tool wear rate is with the minimum value of current and voltage, the minimum average surface roughness for average value of current and voltage.

Harpreet Singh and Amandeep Singh *et al.*, (2012). Compared the material removal rate achieved using different tool materials. Workpiece used is AISI D3 and tool materials used copper and brass electrode with pulse on/pulse off as parameter. The electrolyte used is kerosene oil.

Manish Vishwakarma and Vishal Parashar *et al.*, (2012). Analyzed the influence of operating input parameters of copper electrode on material removal rate of EN-19 material followed by optimization. The effectiveness of EDM process with tungsten copper electrode is evaluated in terms of the material removal rate. In this work the parameters such peak current, voltage gap, pulse on time, duty cycle and flushing pressure were selected. Analysis is carried using the response surface method and Anova analysis.

S R Nipanikar (2012). Analyzed the cutting of D3 Steel material using electro discharge machining (EDM) with a copper electrode by using Taguchi methodology has been reported. It is found that different parameters have a significant influence on machining characteristic such as material removal rate (MRR), electrode wear rate (EWR), radial overcut (ROC). The analysis using Taguchi method reveals that, in general the peak current significantly affects the MRR, EWR and ROC.

Harshadkumar C Patel and Dhaval M Patel *et al*., (2012). Investigate the effect of varying pulse on time, pulse off time, flushing pressure, servo voltage, wire feed rate and wire tension on H-11 material to analyze effect on the Material Removal Rate and Surface finish using ANOVA analysis. A Taguchi design of experiment (DOE) approach with L27 Orthogonal Array employed to conduct this experiment.

Kumar Sandeep, (2013). Reviewed the vast array of research work carried out within past decades for the development of EDM. It is mainly focused on aspects related to surface quality and metal removal rate which are the most important parameters from the point of view of selecting the optimum condition of processes as well as economic aspects. It reports the research trends in EDM.

The literature review reveals that lot of work has been reported on optimization of various output parameters such as Material Removal Rate, Tool Wear Rate, Surface Roughness, etc. by changing various input parameters such as current, voltage, electrode, polarity, duty cycle pulse on time, pulse off time, retract distance etc. Thus the optimization of the process parameters of EDM has a great potential for future research. Hence in this research an investigation have been done on H11 material with conventional copper electrodes and powder metallurgy electrode by varying different machining parameters and their effect on material removal rate (MRR).

EXPERIMENTAL PROCEDURE

Experiments had done on Electric Discharge Machine; model SMART ZNC of Electronica India Pvt. Ltd., Pune with servo head. The workpiece material selected was H11 die tool steel. A piece of size 65 mm × 27 mm × 07 mm is chosen for the study. The workpiece was then properly cleaned to remove dust or unwanted particles. In experimentation the work piece was then weighed on a precision weighing machine and then the workpiece was mounted on the table of the EDM machine. The diameter of electrodes were measured with a micrometer (range 0 to 25 mm; least count 0.01mm; made of Mitutoyo company, Japan) and then each electrode was weighed on weighing machine to get the initial weight of the electrode before machining. Then electrode was clamped on the tool holder of the EDM machine, and its alignment was checked. The depth of cut was set at 0.50 mm for each cut. Then press the autostart button which will maintain the required gap between workpiece and electrode. When the electrode tip touches the surface of work piece, a beep sound was heard. After that fill the area with dielectric fluid and start the machining operation. As the desired depth of cut is reached, machining operation stops automatically. However, the actual depth of cut achieved may not be 0.50 mm because electrode wears out during the machining operation and the decrease in the length of the electrode also gets added in the depth of cut. Hence, for the purpose of finding out MRR, the loss in the weight of the work piece was taken as the criteria, which gives more accurate results. The input values of discharge current, duty cycle and gap voltage were set by using the hand held keyboard for each experiment. The values were taken as per the design of experiment trial conditions using Taguchi method (Table 1). After the each experiment auto flush knob stopped and leaver of the tank lift up so that the carbon contents due to machining are easily flushed out. During the time of lift, machining stops and the electrode was lifted up to facilitate the removal of debris by the flowing dielectric. For next experiment dielectric pump again switched on. The dielectric starts filling the tank and the tank was filled to the required level with the dielectric and the pressure reading was set to the required value as per the design of the experiment. Then the erosion was switched on and also the stop watch is started. When the required depth of 0.50 mm was reached, the machining operation stops automatically. The stop watch was also stopped at that very instant and time of cut (t in seconds) was noted. The drain valve of the tank was opened to flow out the dielectric to the storage tank. A total of 18 experiments were performed (as per Table 1) 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.

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 = (Wwi - Wwf)/ t gm/sec

Where,

Wwi = initial weight of work piece

Wwf = final weight of work piece

t = Machining time

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

Table 1: Design of Experimental Matrix L18 as per Taguchi Method

Exp. No.	A: Electrode Type	B: Peek Current	C: Duty Cycle	D: Gap Voltage	Depth of Cut (mm)
1	Cu	4	0.72	40	0.5
2	Cu	4	0.82	50	0.5
3	Cu	4	0.92	60	0.5
4	Cu	9	0.72	40	0.5
5	Cu	9	0.82	50	0.5
6	Cu	9	0.92	60	0.5
7	Cu	14	0.72	40	0.5
8	Cu	14	0.82	50	0.5
9	Cu	14	0.92	60	0.5
10	Cu-W	4	0.72	40	0.5
11	Cu-W	4	0.82	50	0.5
12	Cu-W	4	0.92	60	0.5
13	Cu-W	9	0.72	40	0.5
14	Cu-W	9	0.82	50	0.5
15	Cu-W	9	0.92	60	0.5
16	Cu-W	14	0.72	40	0.5
17	Cu-W	14	0.82	50	0.5
18	Cu-W	14	0.92	60	0.5

In the present research work, selected input machining parameters with their designation are listed in Tables 2 and 3 shows assigned values of machining parameters at these levels and their designation for experimental work.

Table 2: Input Machining Parameters with their Designation

Machining Parameters	Electrode Type	Peek Current	Gap Voltage	Duty Cycle
Symbol	A	B	C	D

Table 3: Assigned Values of Input Machining Parameters at Different Levels and their Designation

Factor	Machining	Levels and corresponding values of Machining parameter		
Designation	**Parameter (units)**	**Level-1**	**Level-2**	**Level-3**
A	**Electrode Type**	**Conventional Copper**	**Powder Metallurgy Electrode (CuW)**	**xxxxxxxxxxxxxxxxx**
B	**Peak Current (A)**	**4**	**9**	**14**
C	**Gap Voltage (V)**	**40**	**50**	**60**
D	**Duty Cycle**	**0.72**	**0.82**	**0.92**

RESULTS AND DISCUSSION

The results obtained after experimentation on Electrical Discharge Machining of H-11 Die Tool Steel with conventional copper tool electrode (Cu) and powder metallurgy copper-tungsten tool electrodes CuW (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.

Table 4: Experimental Result for MRR

Exp. No.	Weight of workpiece before machinining (gm)	Weight of workpiece after machinining (gm)	Weight of workpiece before machinining-Weight of workpiece after machinining (gm)	Machinining-time (min)	Material removal rate (gm/min)
1	108.435	108.248	0.187	4.42	0.042307692
2	108.248	108.053	0.195	5.05	0.038613861
3	108.053	107.863	0.19	5.34	0.035580524
4	107.863	107.655	0.208	1.34	0.155223881
5	107.655	107.472	0.183	1.32	0.138636364
6	107.472	107.262	0.21	1.34	0.156716418
7	107.262	107.048	0.214	0.51	0.419607843
8	107.048	106.826	0.222	0.48	0.4625
9	106.826	106.635	0.191	1.07	0.178504673
10	106.635	106.42	0.215	5.41	0.03974122
11	106.42	106.182	0.238	5.14	0.046303502
12	106.182	105.944	0.238	6.58	0.036170213
13	105.944	105.695	0.249	1.53	0.162745098
14	105.695	105.451	0.244	1.5	0.162666667
15	105.451	105.208	0.243	2.18	0.11146789
16	105.208	104.953	0.255	1.14	0.223684211
17	104.953	104.71	0.243	1.18	0.205932203
18	104.71	104.451	0.259	1.22	0.212295082

Taguchi method is used to analyze the result of MRR for larger is better criteria. The analysis of variance for SN Ratios for MRR (larger is better) is shown in Table 5 which is clearly indicates that the, electrode type and duty cycle are relatively less influencing factors to MRR. Peak current and gap voltage are the most influencing factors for MRR. Response for SN Ratios for MRR (Larger is better) are shown in Table 6 from the delta values and the rank assigned to various input parameters and by considering the case.

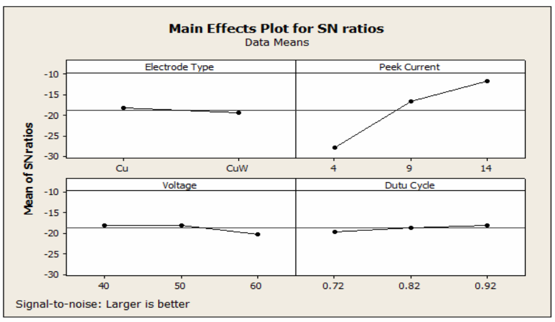
Table 5: Analysis of Variance for SN Ratios for MRR (Larger is Better)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Electrode Type	1	6.685	6.685	6.685	10.13	0.033
Peek Current	2	853.416	853.416	426.708	646.91	0.000
Voltage	2	19.490	30.298	15.149	22.97	0.006
Duty Cycle	2	8.140	16.563	8.282	12.56	0.019
Electrode Type* Peek Current	2	13.886	13.886	6.943	10.53	0.025
Electrode Type* voltage	2	9.995	9.995	4.998	7.58	0.044
Electrode Type* Duty Cycle	2	12.776	12.776	6.338	9.68	0.029
Residual Error	4	2.638	2.638	0.660		
Total	17	927.026				

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

Level	Electrode Type	Peek Current	Voltage	Duty Cycle
1	-18.15	-28.04	-18.00	-19.68
2	-19.37	-16.67	-18.05	-18.51
3		-11.57	-20.23	-18.09
Delta	1.22	16.47	2.23	1.59
Rank	4	1	2	3

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



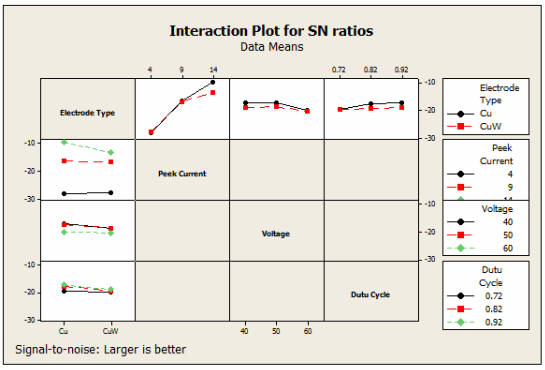
It is clear from fig 1 that MRR is maximum at the 1st level of electrode type, 3rd level of peak current, 3rd level of duty cycle, 1st level of gap voltage.

Table 7: Response Table for SN ratio for MRR (Larger is Better)

Factor	A	B	C	D
Level	1	3	1	3

The mechanism of material removal of EDM process is most widely established principle is the conversion of electrical energy it into thermal energy. During the process of machining the sparks are produced between workpiece material and tool electrode. Thus each spark produces a tiny crater in the material along the cutting path by melting and vaporization, thus eroding the workpiece to the shape of the tool electrode. It is well-known and elucidated by many EDM researchers by Roethel that Material Removal Mechanism (MRM) is the process of transformation of material elements between the work-piece and electrode. The transformation are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a solid, liquid or gaseous phase reaction. In the present work the result shows that the effect of Material Removal Rate is more when conducting the experiments at positive polarity with conventional copper tool electrode. Small mass electrons have more velocity; they strike the workpiece with heavy momentum and with high energy therefore more energy at workpiece erodes more material from workpiece. Material Removal Rate with Powder Metallurgy CuW (Cu75% W25%) is lower than conventional Copper electrode. MRR increases with increase in peek current because of higher erosion of work piece material this is mainly due to more spark between tool and the workpiece hence temperature between tool and workpiece will increases which will automatically increases the MRR. Increase in Duty Cycle means increase in pulse on time and decrease in pulse off time. It is observed that increase in duty cycle leads to increase in MRR. It is due to the reason that with an increase in pulse on time, total machining time and hence total current utilization time increases. Increase in pulse on time retains the spark for more time in spark gap. This means more time the heat is available to melt and vaporize the work material. With regard to gap voltage, MRR decreases when the gap voltage increased. One of the reasons for this could be the higher amount of debris formation and higher flushing required due to increased spark energy at higher voltages. Since, discharge gap increases with an increase in voltage; flushing efficiency is reduced at high voltages. The increase in spark energy is dominated by the reduction in spark efficiency as voltage is increased. This leads to a reduction in MRR

Figure 2: Interaction Plot for SN Ratios



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

1. It was found that A1, B3, C1 and D3 are the best treatment combinations to give maximum MRR.
2. The interaction plot graph shows that interaction between electrode type and peek current is one of the significant influence on the output parameters.
3. MRR increases with the increases in peek current for both electrodes, but it is less with the copper tungsten (CuW) electrode as compared with the copper electrode. The reason behind this is due to the deposition of material from the copper tungsten electrode on the work piece.

4. It is clear from fig 2 that there is weak interaction between the other machining parameters that affecting the MRR, since the performance at different parameters values are almost parallel. These results confirm the results that achieved from Anova Table No. 5.

CONCLUSION

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

1. From the experimental results it was found Electric discharge machining of H-11 die tool Steel is feasible with a conventional copper tool electrode at positive polarity.
2. Electrode type is less significant factor for output parameters.
3. Machining rate increases with the increase in current due to predominant increase in spark energy.
4. Positive polarity with 14amp current, voltage of 40V and duty cycle of 0.92 gives the best results for MRR i.e. A1, B3, C1, D3.

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