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Experimental Investigation of Material Removal Rate on H-13 Using Powder Metallurgy and Conventional Electrodes

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Abstract

Electric discharge machining is most widely used method for machining materials which are used mostly 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 but sufficient data is not available on H-13 even though it is widely used in pressure die casting tools, extrusion tools, forging dies, stamping dies, plastic molds etc. Hence there is a need to investigate the machining of this material with copper chromium (CuCr) electrodes (made through powder metallurgy technique) by varying different machining parameters such as discharge current, gap voltage, duty cycle, polarity, retract distance and flushing pressure and their effect on Material Removal Rate (MRR). It was found that Machining rate increases with the increase in current due to predominant increase in spark energy. Positive polarity with powder metallurgy electrode (80%Cu 20%Cr) at current value (10A) and duty cycle (0.9) gives the best results for MRR.

Keywords : Electric discharge machining, Powder Metallurgy, MRR, Taguchi Method.

Introduction

The history of Electric discharge machining techniques had started as far back as the 1770s when it was discovered by an English Scientist. But EDM was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and Used for machining purposes. Commercially developed in the mid 1970s, wire EDM began to be a viable technique that helped the metal working industry as we see today. In the mid 1980's, the EDM techniques were transferred to a machine tool. This migration made EDM more widely available and used over traditional machining processes. The new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions. With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed. 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. Non-traditional machining methods have grown out due to need to machine these exotic materials. The Non-Traditional 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. Currently, non-traditional processes possess virtually unlimited capabilities except for volumetric material removal rates, for which great advances have been made in the past few years to increase the material removal rates. As removal rate increases, the cost effectiveness of operations also increase, made greater uses of nontraditional process. The EDM process is employed widely for making tools, dies and other precision parts. EDM has been replacing drilling, milling, grinding and other traditional machining operations and is now a well established machining option in many manufacturing industries all over the world. EDM is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys,

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ceramics, carbides, heat resistant steels etc. being widely used in tool and die making industries, aerospace, aeronautics and nuclear industries. EDM has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive R&D areas.

EDM is a thermo-electric non-traditional machining process. In this material is removed from the Workpiece through localized melting and vaporization of material. In EDM 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.

Literature Survey

Simao et al. (2003) [8] 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 aluminum, nickel, titanium etc. **Guu (2005) [3]** analyzed the surface morphology, surface roughness and micro crack of AISI D2 tool steel by means of atomic force microscopy (AFM) technique. An excellent machined finish can be obtained at low pulse energy. The surface roughness and depth of micro-cracks were proportional to power input. **Mohri et al. (2006) [6]** worked on Surface modification with semi-sintered electrodes, worn substances in the gap region form the material source of layer generation on the work surface. **Khanra et al. (2007) [4]** 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. **Beri et al. (2008) [2]** performed experimentation on electric discharge machining of AISID2 steel in kerosene with PM CuW (30% Cu and 70% W) electrode and conventional Cu electrode. An L18 orthogonal array of Taguchi methodology was used to identify the effect of process input factors (current, duty cycle and flushing pressure) on the output factors {material removal rate (MRR) and surface roughness (SR)}. It was found that PM CuW electrode gives high surface finish where as the conventional Cu electrode is better for higher material removal rate. **Kumar et al. (2009) [5]** reported by them that besides erosion of work material during machining, the intrinsic nature of the process results in removal of some tool material also. Formation of the plasma channel consisting of material vapours from the eroding work material and tool electrode; and pyrolysis of the dielectric affect the surface composition after machining and consequently, its properties. Deliberate material transfer may be carried out under specific machining conditions by using either composite electrodes or by dispersing metallic powders in the dielectric or both. **Beri et al. (2011) [1]** correlate the usefulness of powder metallurgy (PM) electrodes in electrical discharge machining (EDM). Experimentation was performed on AISID2 steel in kerosene with CuW (25% Cu and 75% W) PM electrode. Experimental results indicate that electric discharge machining process performance can be improved efficiently through this approach. It is found that copper tungsten PM electrode gives better multi-objective performance than conventional copper electrode. **Singh (2012) [7]** studied the effect of machining parameters such as pulsed current on material removal rate, depth of cut, overcut, tool wear (net weight lost) and hardness on En-31 tool steel using copper chromium and brass electrodes by varying the pulsed current at positive polarity.

Investigations indicate that brass has better depth of cut and hardness while copper chromium, better MRR with lower tool wear.

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, Wear Ratio, Surface Roughness, overcut

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etc. by changing various input parameters such as current, voltage, electrode, polarity, duty cycle pulse on time, pulse off time, retract distance etc. The optimization of the output parameters of the cold chamber die casting is adversely effected by the various input parameters. 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 H13 material with conventional copper electrodes and powder metallurgy electrode by varying different machining parameters and their effect on material removal rate (MRR).

Experimental Procedure

The experiments were carried out on standard Electric Discharge Machine; - model SMART ZNC of Electronica India Pvt. Ltd. Pune with servo head. The workpiece material selected was H-13 steel.

A rectangular piece of size 94 mm × 86 mm × 04 mm is chosen for the study. The workpiece was then properly cleaned with pressurized air jet to remove dust or unwanted particles. The output parameters chosen for study were material removal rate (MRR) at different machining input variables with different compositions of powder metallurgy tool electrodes [CuCr-1 (Cu 80% and Cr10%) and CuCr-2 (Cu 75% and Cr 25%)]. For experimentation the work piece was then weighed on a precision weighing machine and then mounted on the T-slot table of the EDM machine. The diameter of electrodes were measured with a micrometer (range 0 to 25 mm; least count 0.01mm; make Mitutoyo, Japan) and then each electrode was weighed on precision weighing machine to get the initial weight of the electrode before machining. Then electrode was clamped on the V-Block tool holder of the EDM machine and its alignment was checked with the help of a tri-square. The depth of cut was set at 0.50 mm for each cut. When the electrode tip touches the surface of work piece, a beep sound was heard. As the desired depth 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, retract distance 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 Assigned values of input machining parameters at different levels and their designation. Table 1 shows the Design of Experiment as per Taguchi method.

The auto-flush knobs were then set at the desired time of lift and cut of the electrode so that the carbon contents due to machining can 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. Then, the mains supply was switched "ON" followed by dielectric pump. The dielectric starts filling the tank and the tank was filled to the required level with the dielectric 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 for the noting the time of cut is started.

Table 1 shows the Design of Experiment matrix L36 as per Taguchi method

Exp No.	A : Polarity	B : Electrode type	C : Peak Current (Ampere)	E : Duty Cycle	F : Gap Voltage (Volt)	F: Retract Distance
1	Positive	Copper	6	.7	40	1
2	Positive	CuCr-1	10	.8	50	2
3	Positive	CuCr-2	14	.9	60	3
4	Positive	Copper	6	.7	40	2
5	Positive	CuCr-1	10	.8	50	3
6	Positive	CuCr-2	14	.9	60	1
7	Positive	Copper	6	.8	60	1
8	Positive	CuCr-1	10	.9	40	2
9	Positive	CuCr-2	14	.7	50	3
10	Positive	Copper	6	.9	50	1
11	Positive	CuCr-1	10	.7	60	2
12	Positive	CuCr-2	14	.8	40	3
13	Positive	Copper	10	.9	40	3
14	Positive	CuCr-1	14	.7	50	1
15	Positive	CuCr-2	6	.8	60	2
16	Positive	Copper	10	.9	50	1
17	Positive	CuCr-1	14	.7	60	2
18	Positive	CuCr-2	6	.8	40	3
19	Negative	Copper	10	.7	60	3
20	Negative	CuCr-1	14	.8	40	1
21	Negative	CuCr-2	6	.9	50	2
22	Negative	Copper	10	.8	60	3
23	Negative	CuCr-1	14	.9	40	1
24	Negative	CuCr-2	6	.7	50	2
25	Negative	Copper	14	.8	40	2
26	Negative	CuCr-1	6	.9	50	3
27	Negative	CuCr-2	10	.7	60	1
28	Negative	Copper	14	.8	50	2
29	Negative	CuCr-1	6	.9	60	3
30	Negative	CuCr-2	10	.7	40	1
31	Negative	Copper	14	.9	60	2
32	Negative	CuCr-1	6	.7	40	3
33	Negative	CuCr-2	10	.8	50	1
34	Negative	Copper	14	.7	50	3
35	Negative	CuCr-1	6	.8	60	1
36	Negative	CuCr-2	10	.9	40	2

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 36 experiments were performed and at end of each experiment electrode was taken out and was weighed

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to find out the final weight after cut. Similarly, the work piece was removed and weighed to find out final weight. This value also becomes the initial weight for the next cut. Then diameter of the crater (Dc in mm) was measured by taking 3-4 readings with the help of Profile Projector. 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.

Measurement of Material Removal Rate (MRR)

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 and tool .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. 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. The material MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time.

MRR = (Wwi - Wwf)/ t gm/sec

Where,
Wwi = initial weight of work piece
Wwf = final weight of work piece
t = Machining time

In the present research work, selected input machining parameters with their designation are listed in table 1 and table 2 enlists levels of machining parameters and assigned values of machining parameters at these levels and their designation for experimental work.

Table 2 Input machining parameters with their designation

βMachining Parameter	Polarity	Electrode type	Peak Current (amp)	Duty Cycle	Gap Voltage (Volt)	Retract Distance
Symbol	A	B	C	D	E	F

Table 3 Assigned values of input machining parameters at different levels and their designation

Factor Designation	Machining Parameter	Levels and corresponding values of Machining parameter		
		LEVEL-1	LEVEL-2	LEVEL-3
A	Polarity	Positive	Negative	--------
B	Electrode Type	Conventional Copper	Powder Metallurgy Electrode (CuCr-1)	Powder metallurgy Electrode (CuCr-2)
C	Peak Current	6A	10A	14A
D	Duty Cycle	0.7	0.8	0.9
E	Gap Voltage	40V	50V	60V
F	Retract Distance	1mm	2mm	3mm

Results And Discussion

The results obtained after experimentation of Electrical Discharge Machining on H-13 steel with conventional copper tool electrode (Cu) and powder metallurgy copper-chromium tool electrodes CuCr-1 (80%Cu and 20%Cr) and CuCr-2 (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.

Analysis of Material Removal Rate (Larger is Better)

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 4 which is clearly indicates that the peak current, electrode type and gap voltage are relatively less influencing factors to MRR. Polarity, duty cycle and retract distance are the most influencing factors for MRR. Response for SN Ratios for MRR (Larger is better) are shown in table 5 from the delta values and the rank assigned to various input parameters and by considering the case

"MRR: larger is better", it is clear that Retract distance is the most significant factor and gap voltage is the least influencing factor.

Table 4 Analysis of Variance for SN Ratios for MRR (Larger is Better)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Polarity	1	971.4	971.4	971.39	11.67	0.002
Electrode Type	2	717.3	717.3	358.65	4.31	0.025
Current	2	655.1	655.1	327.55	3.93	0.033
Duty Cycle	2	799.6	799.6	399.80	4.80	0.018
Gap voltage	2	591.3	591.3	295.64	3.55	0.045
Retract Distance	2	2473.3	2473.3	1236.64	14.85	0.000
Residual Error	24	1998.4	1998.4	83.26		
Total	35	8206.3				

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Table 5 Response Table for SN ratio for MRR (Larger is Better)

Level	Polarity	Electrode Type	Peak Current (Ampere)	Duty Cycle	Gap Volt. (Volt)	Retract Distance (µm)
1	-31.76	-40.27	-38.86	-34.09	-33.72	-26.34
2	-42.15	-30.64	-31.04	-43.60	-34.47	-26.34
3		-39.94	-40.95	-33.17	-42.67	-37.94
Delta	10.39	9.63	9.91	10.43	8.95	20.23
Rank	3	5	4	2	6	1

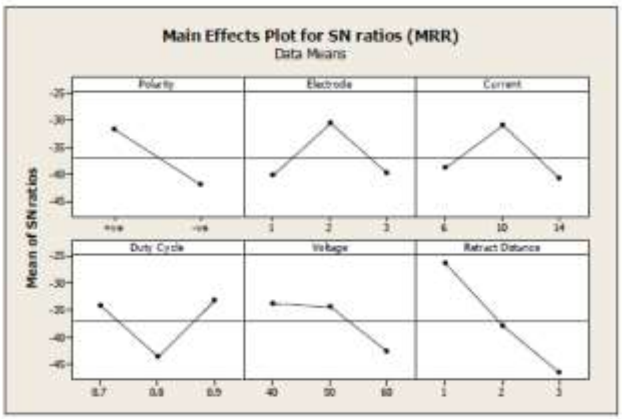

Fig. 1 Main effects plot for SN ratios (MRR)

It is clear from fig 1 that MRR is maximum at the 1st level of polarity, 2nd level of electrode type, 2nd level of peak current, 3rd level of duty cycle, 1st level of gap voltage, 1st level of retract distance.

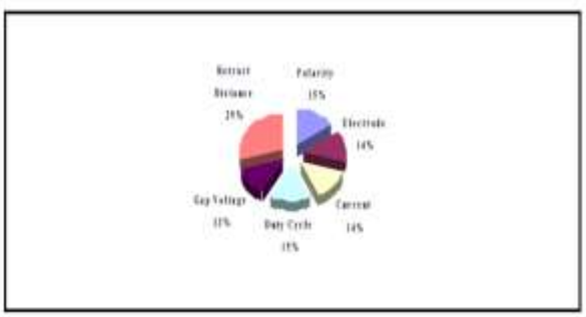

Fig. 2 Percentage contribution of input parameters in MRR

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 Powder metallurgy tool electrode as compare to conventional tool electrode. In positive polarity the electrons flow towards workpiece and positive charged ions flows towards 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. However, in negative polarity, reverse effect is the case. Here heavy mass ions flow towards the workpiece and strike it with less momentum which erodes less material from workpiece and result shows the minimum Material Removal Rate. Material Removal Rate with Powder Metallurgy CuCr1 (Cu90% Cr10%) is highest than conventional Copper electrode and Powder Metallurgy CuCr2 (Cu85% Cr15%). This low MRR followed from the adding of more Cr powder, making the resin inside the Cu powder unable to bond sufficiently with Cr powder, reducing the bonding strength. Thus during machining, powder easily drops out of the electrode and accumulates on the surface of workpiece, disturbing the stability and efficiency of machining. MRR is highest with Powder Metallurgy CuCr1 (Cu90% Cr10%) electrode from low value of current to average value of current but decreases with the further increase in current as with the increase of the current the bonding between the Copper and Chromium metal powder decreases as a result of metal powder easily drops out of the electrode and accumulates on the surface of work piece, disturbing the stability and efficiency of machining**.** 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;

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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. With the increase in retract distance MRR decreases as more time is for the flushing jet to remove the debris from the crater. If the retract distance is small less time for the jet to remove the debris from the crater as these debris act as an abrasive for the cut. From fig. 4.2 it is clear that retract distance contributes maximum (29%) in MRR.

Conclusions

Following conclusions can be drawn from the analysis of the results:
1. From the experimental results it was found Electric discharge machining of H-13 Steel is feasible with a CuCr Powder Metallurgy Electrodes with positive and negative polarity.
2. Electrode type is significant factor for output parameters.
3. Machining rate increases with the increase in current due to predominant increase in spark energy. Positive polarity with powder metallurgy electrode (90%Cu 10%Cr) at current value (10A) and duty cycle (0.9) gives the best results for MRR.
4. Powder metallurgy CuCr electrode gives better MRR and dimensional accuracy in
comparison with conventional copper electrode.

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