An Experimental Study for Material Removal Rate in EDM Using Tool of Graphite, Copper & Silver

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Abstract:
The electrical discharge machining (EDM) is one of the latest non-traditional machining processes, based on thermoelectric energy between the workpiece and tool. The performance of the process, to a large extent, depends on the tool material, workpiece material & manufacturing method of the tool. A suitable selection of tool can reduce the cost of machining. The performance of EDM is find out on the basis of Material Removal Rate (MRR), Overcut (OC), Tool Wear Rate (TWR) and Surface Roughness (SR). The important machining parameters of EDM which affecting on the performance parameters are discharge current, pulse on time, pulse off time, arc gap, flushing pressure, voltage and duty cycle. Taguchi design of experiments is used to conduct experiments by varying the parameters current, pulse on time and pulse off time. The process performance is measured in terms of Material Removal Rate (MRR). In this research EDM experiment using Graphite, Copper & Silver tool & AISI 304 Stainless Steel workpiece has been done for optimizing MRR and reducing cost of manufacturing. Finally it is found that the copper tool is more suitable. In certain characteristics silver tool gives better performance but the cost becomes high for machining so keeping in mind cost and other some characteristics a graphite tool is more suitable than silver tool. The experimental results indicate that the current significantly affects the MRR followed by pulse on time & pulse off time.

Keywords: *Electrical Discharge Machining, MRR, OC, SR, TWR*

1. Introduction

Electric Discharge Machining (EDM) is a nontraditional machining process in the sense that they do not employ traditional tools for metal removal and instead directly by means of electric spark erosion [40]. It is developed in the late 1940s, has been accepted worldwide as a standard process in manufacture of forming tools to produce plastics mouldings, die castings, forging dies etc. 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 [1].

The recent developments in the field of EDM have progressed due to the growing application of EDM process and the challenges being faced by the modern manufacturing industries, from the development of new materials that are hard and difficult-to-machine such as tool steels, composites, ceramics, super alloys, hastalloy, nitralloy, waspalloy, nemonics, carbides, stainless steels, heat resistant steel, etc. being widely used in die and mould making industries, aerospace, aeronautics, and nuclear industries. Many of these materials also find applications in other industries owing to their high strength to weight ratio, hardness and heat resisting qualities. EDM has also made its presence felt in the new fields such as sports, medical and surgical instruments, optical, dental and jewellery industries, including automotive R&D areas [1].

The adequate selection of manufacturing conditions is one of the most important aspects to take into consideration in the die-sinking electrical discharge machining (EDM) of conductive steel, as these conditions are the ones that are to determine such important characteristics: Material Removal Rate (MRR), Overcut(OC), Surface Roughness (SR) and Tool Wear Rate (TWR)[2]. In this paper, a study of Material Removal Rate performed on the influence of the factors of Current, Pulse on Time & Pulse off Time.

2. Principle of EDM

In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system shown in fig 1. Both tool and work piece are submerged in a dielectric fluid Kerosene/EDM oil/de-ionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases. Basically, there are two different types of EDM: Die-sinking EDM & Wire-cut EDM. A EDM system has four major Components: (1) Computerized Numerical Control (CNC), (2) Power Supply, (3) Mechanical Section : Worktable, work stand, taper unit etc., (4) Dielectric System[39].

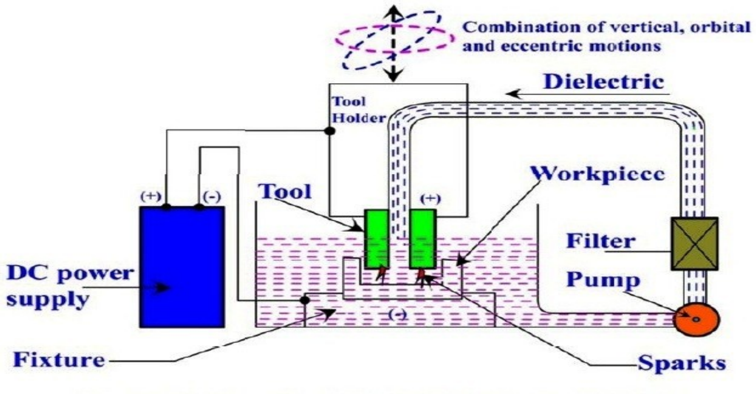

Fig 1. Setup of EDM [1]

3. Existing Research Efforts

Shankar Singh et. al. [1] evaluate that Electric Discharge Machining (EDM), a ‘non-traditional machining process’, has been replacing drilling, milling, grinding and other traditional machining operations and is now a well-established machining option in many manufacturing industries throughout the world. This paper reports the results of an experimental investigation carried out to study the effects of machining parameters such as pulsed current on material removal rate, diameteral overcut, electrode wear, and surface roughness in electric discharge machining of En-31 tool steel (IS designation: T105 Cr 1 Mn 60) hardened and tempered to 55 HRc. The work material was ED machined with copper, copper tungsten, brass and aluminium electrodes by varying the pulsed current at reverse polarity. Investigations indicate that the output parameters of EDM increase with the increase in pulsed current and the best machining rates are achieved with copper and aluminium electrodes. After analysing the results of the experiments on En-31 tool steel with different electrode materials, the following conclusion are arrived at: For the En-31 work material, copper and aluminium electrodes offer higher MRR. Diameteral overcut produced on En-31 is comparatively low when using copper and aluminium electrodes, which may be preferred for En-31 when low diameteral overcut (higher dimensional accuracy) is the requirement. Copper and copper–tungsten electrodes offer comparatively low electrode wear for the tested work material. Aluminium electrode also shows good results while brass wears the most, of all the tested electrodes.Of the four tested electrode materials, Cu and Al electrodes produce comparatively high surface roughness for the tested work material at high values of currents. Copper–tungsten electrode offers comparatively low values of surface roughness at high discharge currents giving good surface finish for tested work material. Copper is comparatively a better electrode materials as it gives better surface finish, low diameteral overcut, high MRR and less electrode wear for En-31 work material, and aluminium is next to copper in performance, and may be preferred where surface finish is not the requirement.

Othman Belgassim et. al. [40] used L9 orthogonal array based on Taguchi method to conduct a series of experiments to optimize the EDM parameters. Experimental data were evaluated statistically by analysis of variance (ANOVA). The EDM parameters are Pulse current (Ip), Pulse –on- time (Ton), Pulse –off- time (Toff), and the Gap voltage (Vg) , while the machining responses in concern are the surface roughness of the machined surface and the over-cut. The experimental results have given optimal combination of input parameters which give the optimum surface finish of the EDM surface.

S.H.Tomadi et. al. [2] evaluate that the influence of operating parameters of tungsten carbide on the machining characteristics such as surface quality, material removal rate and electrode wear. The effectiveness of EDM process with tungsten carbide, WC-Co is evaluated in terms of the material removal rate, the relative wear ratio and the surface finish quality of the workpiece produced. It is observed that copper tungsten is most suitable for use as the tool electrode in EDM of WC-Co. Better machining performance is obtained generally with the electrode as the cathode and the workpiece as an anode. In this paper, a study was carried out on the influence of the parameters such peak current, power supply voltage, pulse on time and pulse off time. The surface quality that was investigated in this experiment was surface roughness using perthometer machine. Material removal rate (MRR) and electrode wear (EW) in this experiment was calculated by using mathematical method. The result of the experiment then was collected and analyzed using STATISTICA software. This was done by using the design of experiments (DOE) technique and ANOVA analysis.

Subramanian Gopalakannan et. al. [25] study the effect of pulsed current on material removal rate, electrode wear, surface roughness and diameter overcut in corrosion resistant stainless steels viz., 316 L and 17-4 PH. The materials used for the work were machined with different electrode materials such as copper, cop-per-tungsten and graphite. It is observed that the output parameters such as material removal rate, electrode wear and surface roughness of EDM increase with increase in pulsed current. The results reveal that high material removal rate have been achieved with copper electrode whereas copper-tungsten yielded lower electrode wear, smooth surface finish and good dimensional accuracy.

V.Balasubramaniam et. al. [31] used different electrode materials namely copper, brass and tungsten while EDM of Al-SiCp Metal Matrix Composite. Material Removal Rate (MRR), Electrode Wear Rate (EWR) and Circularity (CIR) are considered as the performance measures. Artificial Neural Network is used for optimization of the machining parameters such as current, pulse on time and flushing pressure. Investigations indicate that the current is the most significant parameter. Among the three electrodes copper yields better performances. Machining time is reduced with better performances.

Praveen Kumar Singh et. al. [38] focused on the effect of Copper and Brass electrodes on material removal rate (MRR) and tool wear rate (TWR) for AISI D2 tool steel by using Die- Sinker EDM. The current was varied from 4 to 10 amp, the voltage and flushing pressure were constant, the MRR for copper electrode was in the range of 4.8139 -22.6580 mm3/min whereas the range of MRR for brass electrode was 7.2213-9.8203 gm/min. The trend of TWR as shown in results increases with current for both the electrodes. The effect of voltage on MRR and TWR for both the electrodes was analyzed. The MRR for copper electrode was continuously decreasing with voltage whereas MRR for brass don't follow any specific trend. The TWR for both the electrodes decreases with voltage. It has been observed that copper electrode is the best for machining AISI D2 tool steel by using Die- Sinker EDM.

4. Objectives

Encouraging the use of AISI 304 Stainless Steel due to its good weldability, resistance against corrosion & chemicals, good machinability, and good heat resistance. Finding out the best suitable tool material for machining AISI 304 Stainless Steel depending upon requirements such as MRR which directly affects quality of machining and machining time.

5. Experimental setup & DOE

The electric discharge machine, model SPARKONIX SN-25 (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. Spark Erosion EDM oil was used as dielectric fluid.

Material to be used as workpiece- AISI 304 Stainless Steel

Electrode to be used- Graphite, Copper, Silver, all of have 10.00 mm diameter.

Variable Input Parameters- Current, Pulse on time, Pulse off time.

Constant Input Parameter- Voltage[50 V], Flushing Pressure[0.5 lb/m^2]

Depth of Cut- 3 mm

Square work piece has to be machined with each side of 25 mm & 20 mm Thickness.

Experiment has to be done at Jayvir Engineering, Ahmadabad.

DOE Adopted : Taguchi L9 Orthogonal Array

MRR is calculated by, MRR = [Weight of Workpiece before Machining – Weight of Workpiece after Machining] / [Machining Time * Density of Workpiece]

Table 1. Chemical composition of AISI 304 Stainless Steel

Material	C	Cr	Fe	Mn	Ni	P	S	Si	N
AISI304 Wt. %	Max 0.08	18-20	66.345-74	Max 2	8-10.5	Max 0.045	Max 0.03	0.75	0.1

Typical Application of AISI 304 Stainless Steel in : Chemical Equipments, Cooking Equipments, Cooling coil, Evaporators, Food Processing Equipments, Hospital Equipments, Refrigerator Equipments, Paper & Rubber Industry.

Technical Reasons for Selecting Graphite: Graphite is the preferred electrode material for 90% of all sinker EDM applications. Graphite has an extremely high melting point about 5530 ◦C. Graphite has significantly lower mechanical strength properties than metallic electrode materials. Easily available & low in cost [2].

Technical Reasons for Selecting Copper: Copper can produce very fine surface finishes. Also Copper has high electrical conductivity [1.04 * 10^7 Siemens/meter], Sufficiently high melting point [1083 °C]. Easily available & low in cost [2].

Technical Reasons for Selecting Silver: Silver is occasionally used as an electrode material, due to its superior electrical conductivity, purity, and structural integrity. The use of Silver electrodes and fine finish power supplies can produce extraordinary fine finishes in coining dies. Easily available [2].

The L9 Orthogonal Array methodology has been used to plan the experiments. Three factors are chosen the design becomes a 3 level 3 factorial Taguchi design. The version 16 of the MINITAB software was used to develop the experimental plan for L9 Orthogonal Array.

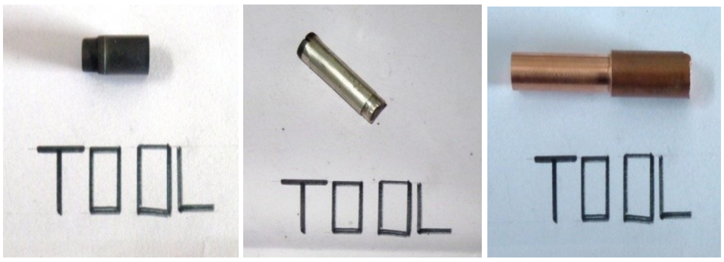

Fig 2. Tool Material : Graphite, Silver, Copper

Table 2. Factors with Levels

Factors	Notation	1	Levels 2	3
Current (Amps)	Ip	4	8	15
Pulse on Time (μs)	Ton	5	6	7
Pulse off Time (μs)	Toff	4	5	6

6. Experimental Result & Discussion

The effect of process parameters on the machining parameter is recorded in the table. The nine experiments done on the electro discharge machine based on the Taguchi method and summarized in the following table.

Table 3. Design Layout and Experimental Results

Run No.	Current (Amps)	Pulse on Time (μs)	Pulse off Time (μs)	MRR (mm^3/min) Graphite Tool	MRR (mm^3/min) Copper Tool	MRR (mm^3/min) Silver Tool
1.	4	5	4	0.00000366	0.00000525	0.00000532
2.	4	6	5	0.00000288	0.00000446	0.00000471
3.	4	7	6	0.00000130	0.00000249	0.00000359
4.	8	5	5	0.00001662	0.00001608	0.00001923
5.	8	6	6	0.00001081	0.00001714	0.00001780
6.	8	7	4	0.00000360	0.00002216	0.00001140
7.	15	5	6	0.00002052	0.00002953	0.00002826
8.	15	6	4	0.00001915	0.00003979	0.00002374
9.	15	7	5	0.00001146	0.00004825	0.00002093

Fig 3. Tool & Workpiece Material after Machining : Graphite, Copper, Silver

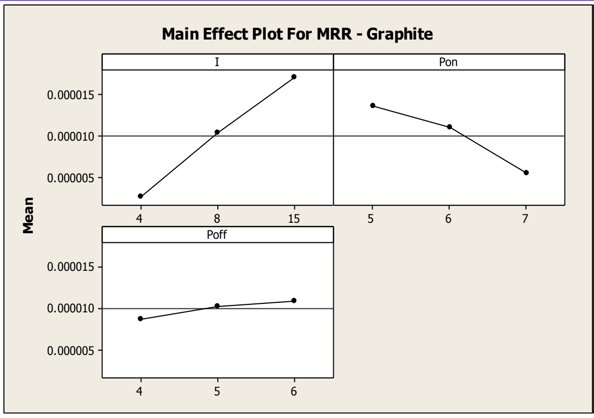

Fig 4. Main effect of process parameters on MRR

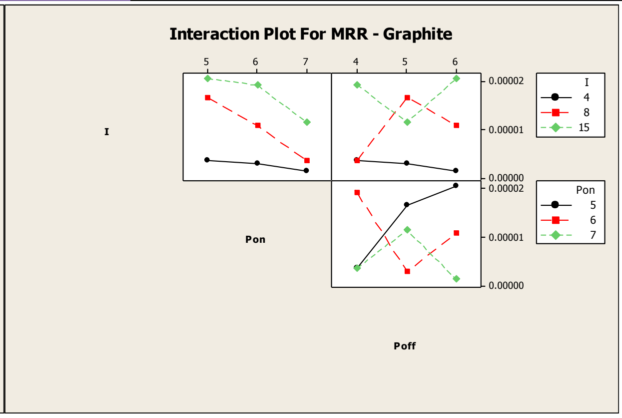

Fig 5.Interaction effect of process parameters on MRR

Figure 4 shows the main effect plot of process parameters on MRR at different parameters like current, pulse on time, pulse off time in EDM process of machining for AISI 304 SS by graphite tool. From the figure, it can be seen that :-
Effect of Current : MRR is increase with the increase in Current.
Effect of Pulse on Time : MRR is decrease with the increase in Pulse on Time.
Effect of Pulse off Time : MRR is a slight increase with the increase in Pulse off Time.

Figure 5 shows the interaction effect plot of process parameters on MRR at different parameters like current, pulse on time, pulse off time in EDM process of machining for AISI 304 SS by graphite tool.

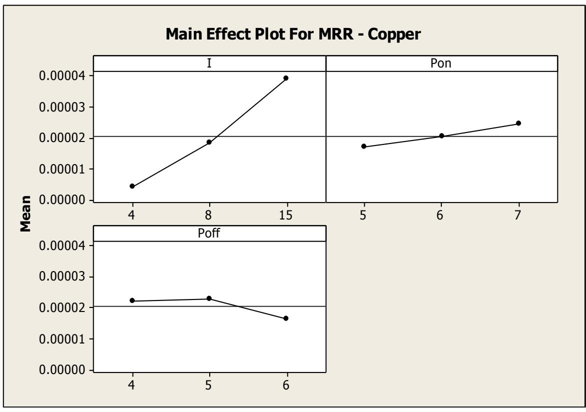

Fig 6.Main effect of process parameters on MRR

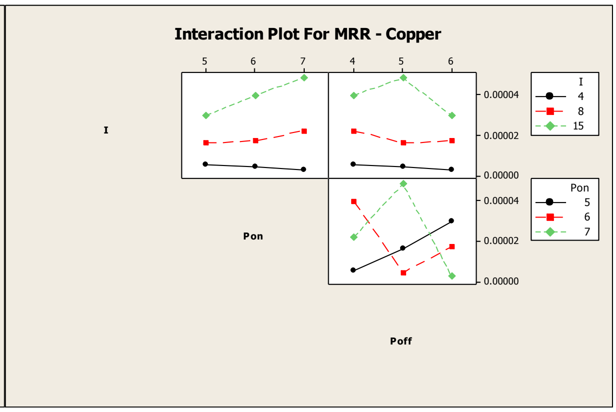

Fig 7.Interaction effect of process parameters on MRR

Figure 6 shows the main effect plot of process parameters on MRR at different parameters like current, pulse on time, pulse off time in EDM process of machining for AISI 304 SS by copper tool. From the figure, it can be seen that :-
Effect of Current : MRR is increase with the increase in Current.
Effect of Pulse on Time : MRR is increase with the increase in Pulse on Time.
Effect of Pulse off Time : MRR is a slightly decrease with the increase in Pulse off Time.

Figure 7 shows the interaction effect plot of process parameters on MRR at different parameters like current, pulse on time, pulse off time in EDM process of machining for AISI 304 SS by copper tool.

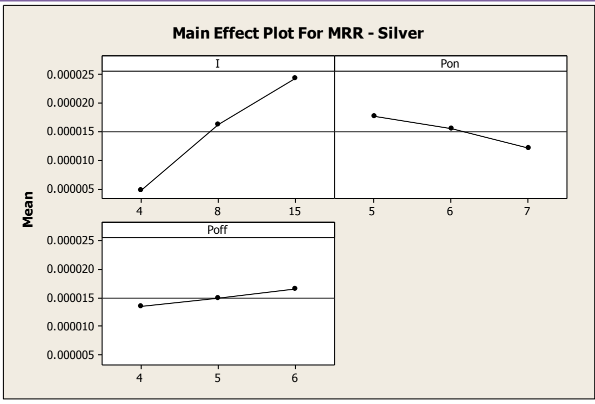

Fig 8.Main effect of process parameters on MRR

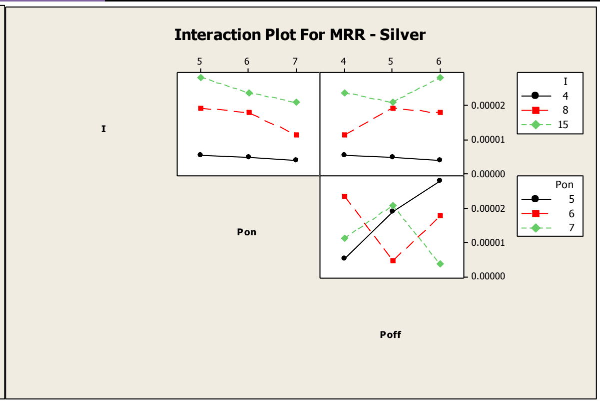

Fig 9. Interaction effect of process parameters on MRR

Figure 8 shows the main effect plot of process parameters on MRR at different parameters like current, pulse on time, pulse off time in EDM process of machining for AISI 304 SS by silver tool. From the figure, it can be seen that :-
Effect of Current : MRR is increase with the increase in Current.
Effect of Pulse on Time : MRR is decrease with the increase in Pulse on Time.
Effect of Pulse off Time : MRR is a slight increase with the increase in Pulse off Time.

Figure 9 shows the interaction effect plot of process parameters on MRR at different parameters like current, pulse on time, pulse off time in EDM process of machining for AISI 304 SS by silver tool.

7. Conclusion

Effect of process parameters on MRR for Graphite tool was concluded as under :

- Effect of Current : MRR is increase with the increase in Current.
- Effect of Pulse on Time : MRR is decrease with the increase in Pulse on Time.
- Effect of Pulse off Time : MRR is a slight increase with the increase in Pulse off Time.

Effect of process parameters on MRR for Copper tool was concluded as under :

- Effect of Current : MRR is increase with the increase in Current.
- Effect of Pulse on Time : MRR is increase with the increase in Pulse on Time.
- Effect of Pulse off Time : MRR is a slightly decrease with the increase in Pulse off Time.

Effect of process parameters on MRR for Silver tool was concluded as under :

- Effect of Current : MRR is increase with the increase in Current.
- Effect of Pulse on Time : MRR is decrease with the increase in Pulse on Time.
- Effect of Pulse off Time : MRR is a slight increase with the increase in Pulse off Time.

Finally it is found that the copper tool is more suitable. In certain characteristics silver tool gives better performance but the cost becomes high for machining so keeping in mind cost and other some characteristics a graphite electrode is more suitable than silver tool. The experimental results indicate that the current significantly affects the MRR followed by pulse on time & pulse off time.

8. Future Scope

Various theoretical models describing overcut mechanism have been proposed by the researchers from time to time. Still a lot of in-depth study is required to better understanding and development of the EDM process. Future scope which would express this research is some non-electrical parameters like electrode rotation and work piece rotation while machining improve the flushing conditions and thus may increase MRR. Performance of water based dielectric is yet to be investigated for machining materials like composites and carbides. Selection of different types of electrode would also change in overcut. It may also be used the hybrid Electric Discharge Machine such as Abrasive and Dielectric mixture EDM, Magnetic EDM, etc.

Acknowledgement

The author is very grateful to Mr. Ronak Punchal , Owner of Jayvir Engineering, Nikol, Ahmadabad for providing the material and machinery for experimentation.

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