Analysis and Optimization of Tool Wear in EDM Process – A Review

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Abstract— Electrical discharge machining is a non-traditional machining process that involved a transient spark discharges through the fluid due to the potential difference between the electrode and the work piece. Improper choose of electrode material in EDM may result highly poor machining performance and electrode wear that would increase the cost of production. This papers reviews research for optimization of various parameters in the experimentation on EDM by using Taguchi Method as a Design of Experiment and response for Tool Wear Rate(TWR).In the study main objectives of the best selection of electrode material for EDM machining provides longer tool life, lower tool wear and machining accuracy.

Key words: EDM, Tool Wear Rate(TWR), Taguchi Method

I. Introduction

The erosive effect of electric discharge was first noted in 1770s by English physicist joseph priestley. Electric Discharge Machining is one non-traditional Machining Process. Now a days due to need for high strength materials in sophisticated industries and patronage by the advances in the field of Materials science, there has been an increase in the availability and use of different machining of materials. It was invented by two Russian scientists. EDM performance is generally evaluated on the basis of Material removal rate (MRR), Tool wear rate (TWR), and Surface roughness (SR). EDM widely used for Manufacturing Dies, automotive parts surgical and aerospace components. The important EDM parameters affecting to the performance measures of the process are Discharge current, Pulse on time, Pulse off time, spark gap, voltage and duty cycle. Analytical and statical Methods are used to select best combination of process parameters for an optimum machining performance. Different researcher use different process parameters and they analyses the experimental data by plotting graphs.

Some other methods used by researchers for analysis of taguchi's DOE data related to Electric Discharge Machining.

A. Principle of EDM

It is works on the principle of thermo-electric effect. When such a DC pulse is delivered to the electrodes a breakdown of the electric field occurs due to ionosation of the dielectric fluid at the point where the distance between the surface irregularities on the tool and the workpiece is the shortest. This leads to the formation of a conducting electric path and a spark occurs. Midway through the pulse the voltage across the gap is decreased and the current is stepped up by the power supply. This increases both the temperature and the pressure in the spark channel. A small amount of material from the surface of the workpiece and tool is melted and vaporized by this temperature. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system shown in fig. Both tool and work piece are submerged in a dielectric fluid. Kerosene/ EDM oil/ deionized water is very common type of liquid dielectric fluid. The tool is of cathode and work piece is anode. The mechanical set up and electrical set up shown in fig 1.

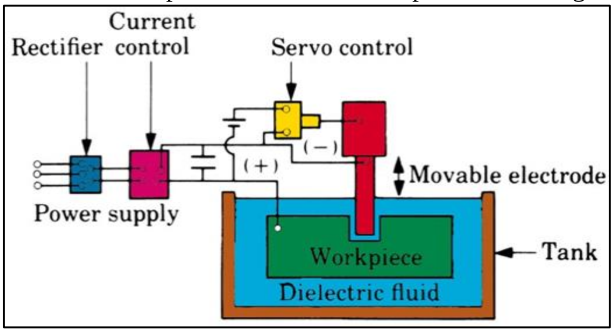

Fig. 1: Schematic Diagram Of EDM Process

B. Specifications of EDM

Mechanism of Process	Melting and evaporation with the help of high energy spark
Medium	Dielectric fluid
Work material	Any electrically conductive material
Tool material	Copper, brass, copper tungsten alloy, silver tungsten alloy, graphite, aluminium
Gap	10 to 120 microns
Voltage	30- 250 V
Current	5 – 60 A
Temperature	10000° C
Dielectric	Petroleum based hydrocarbon fluids, silicon- based oils , De-ionized water, Kerosene, Liquid paraffin
Maximum metal removal rate	5000 mm^3/min
Surface finish produced	2-12 microns
Specific power consumption	1.8 W / mm^3 / min
Wear ratio	0.1 to 10

Table 1: Specification of EDM

II. Methods and Material

A. Taguchi Methodology

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings "of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. After World War II, the Japanese manufacturers were struggling to survive with very limited resources. If it were not for the advancements of Taguchi the country might not have stayed afloat let alone flourish as it has. Taguchi revolutionized the manufacturing process in Japan through cost savings.

B. *Tool Material*

Tool material should be such that it would not undergo much tool wear when it is impinged by positive ions. Thus the localized temperature rise has to be less by tailoring or properly choosing its properties or even when temperature increases, there would be less melting. The tool material should thus have the following characteristics:

- High electrical conductivity.
- High thermal stability.
- High melting temperature.
- Ability to produce high metal removal rate and good surface finish.
- Low tool wear rate.
- Good manufacturability.
- Low cost

List of Tool material which are used in EDM & why they are used?

1) Copper

Pure copper or electrolytic grade copper is a very useful tool material when fine finish is required on the work piece. It can be easily manufactured by casting of machining. Electrodes with very complex features are formed by chemical etching or electroforming. When grinding copper tools for good surface finish however a lot of wheel loading takes place. Copper is recommended for holes and slots but not recommended for high accuracy and details.

2) Tellurium copper

It has performance characteristics similar to copper but has a very good machinability almost as good a that of free machining brass. The main disadvantage of tellurium copper is its poor availability.

3) Brass

Free machining brass is often used as an electrode material particularly for drilling of small holes. It is easily availably and can be readily machined. It has proved quite useful for machining some titanium alloys under poor chip removal conditions. Brass cannot be used for machining hard materials like tungsten carbide because of its wear rate. 1 and 6 is wear ratio of Brass.

4) Copper tungsten

Copper tungsten is a sintered electrode where copper infiltrates the tungsten powder. It has a good wear rate and produces excellent surface finish. It is used for making small and medium sized electrodes of intricate shape. It is not recommended for large areas.

5) Tungsten

Tungsten has high rigidity and a good wear ratio. It is used for making holes less than 0.2 mm when other electrode materials are not available. The main disadvantages of tungsten is its high cost and difficulty in machining. It is most suitable for irregular holes.

6) Zinc Alloys

Zinc alloys are useful for high production where large numbers of identical electrodes are required Complex shapes of zinc alloy electrodes can easily be produced by pressure die casting or coining. The cost of the electrode is low. High currents up to 150 amperes can be used with these electrodes.

7) Graphite

Among the non-metals and non-metals combinations graphite and copper graphite are by for the best materials available for the electrode. Graphite is the most widely used electrode material. It is comparatively cheap, is easily available and offers best stability. Can be easily formed by machining, moulding, grinding etc. Give better material removal rate compared to met5allic tool electrodes with less wear. Coarse grained graphite is used for large volume work while fine grained graphite of high density is used where better details or accuracy is desired. Graphite however has a propensity for arcing and needs ant arcing devices to be incorporated in the set up.

8) Copper graphite

Copper graphite is graphite in filtered with copper. It has better rigidity then graphite and combines the characteristics to both copper and graphite. It works well under poor flushing conditions and is good for machining tungsten carbides. It is recommended for general purpose work. The main draw backs of copper graphite are its higher coener wear rate a cost which is 50 to 100 percent more than graphite.

III. PROCESS PARAMETERS

There is many input parameters for Die-sinker EDM are machining parameters like as pulse on time, pulse off time, flushing pressure, voltage output parameters are surface roughness, tool wear rate and material removal rate.

A. *Pulse on Time (Ton)*

The pulse on time is referred as Ton and it represents the duration of time in micro seconds (µs). During the pulse on time, the voltage is applied in the gap between work piece and the electrode thereby producing discharge. Higher the pulse on time, higher will be the energy applied there by generating more amount of heat energy during this period.

B. *Pulse Off Time (Toff)*

The pulse off time is referred as Toff and it represents the duration of time between the two simultaneous sparks is also expressed in micro seconds. This is the time between discharges. Off Time has no effect on discharge energy. Off Time is the pause between discharges that allows the debris to solidify and be flushed away by the dielectric prior to 28 the next discharge. With a lower value of Toff, there is more number of discharges in a given time, resulting in increase in the sparking efficiency. As a result, the cutting rate also increases.

C. *Peak Current (Ip)*

Peak current is the amount of power used in discharge machining and is measured in unit of amperage. During each pulse on-time, the current increases until it reaches a preset level, which is expressed as the peak current. Higher amperage is used in roughing operations and in cavities or details with large surface areas. Higher currents will improve MRR, but reduce the surface roughness.

D. Voltage

Gap voltage or open circuit voltage specifies the supply voltage to be placed on the gap. Greater the gap voltage, greater will be the electric discharge. If the gap voltage increases, the peak current will also increase. The open gap voltage is the voltage read across the electrode and work piece space prior to the spark.

IV. LITERATURE REVIEW

Literature review provides the scope for the present study. This chapter will play a part to get the information about electrical discharge machine and will give idea to operate the test and form the early stage of the projects; various literature studies have been done. This chapter includes almost the whole operation including the test, history, machining properties and results. In this chapter we have included research papers related to DIE-SINKER EDM, WEDM with effect on Material Removal Rate (MRR), Tool wear rate, Surface Roughness (SR).

S.R. Nipanikar have study variation of cutting performance with pulse on time, Peak current, Duty cycle, Gap voltage were experiment investigated in electric discharge machining processes. Copper electrode and AISI D3 steel were used as tool and work materials. The output considered has been MRR, EWR and Overcut (OC). Experimentation has been competed by using Taguchi's L9 orthogonal array under different conditions of parameters. It has been observed that there is one particular level for each factor for which the responses are either maximum (in case of MRR) or minimum(in case of EWR). Finally it concluded that the material removal rate(MRR) mainly affected by peak current. Duty cycle has least effect on it. The electrode wear rate (EWR) is mainly influenced by peak current. The effect of gap voltage is less on EWR and has least effect on it. Peak current have the maximum effect on the radial overcut (ROC). The gap voltage has least effect on it. Optimum parameters of input factors are as follows; Ton: 75µs Ip: 8Amp t:12 Vg:55 volt.

Nibu Mathew studied electric discharge machining of H11 chromium hot work tool steel. Experimentation has been done by using Taguchi's L18 orthogonal array under different conditions of parameters. Two kinds of tool electrode materials mainly conventional copper tool electrode (99%Cu) made from powder metallergy techniques (75%Cu and 25%CuW) was used. Spark gap which was maintained by a distance of 0.02mm, depth of cut 0.50 mm and dielectric fluid of standard EDM oil are the constant parameter in this study. Cuw electrode made through powder metallurgy is of diameter 8.00 mm and a length of 90mm respectively. Have study Variation of Cutting parameters Polarity, Voltage, Pulse on-time, Duty cycle etc. Observed that with powder metallurgy copper tungsten (75%Cu and 25%W) tool electrode, tool wear decreases continuously with increase in peak current. TWR deacreases with the increase in voltage up to 50 volt and after the TWR increases with the increase in voltage for conventional copper tool electrode. For metallergy copper tungsten tool electrode it is observed that TWR decreases with increase in voltage up to 50 volt and after that TWR increases continuously up to 60 volt. Finally it was found that powder metallurgy tool electrode (CuW) gives better TWR as compared to conventional electrode.TWR increases with the increase in peak current, gap voltage and duty cycle.

M M Rahman, M. A. R. Khan have studied on Experimental investigation into EDM of stainless steel 304.they used cylindrical copper as electrodes with positive polarity. The electrode used is 19 mm in diameter and 37 mm in height & used austenitic stainless steel 304 as a work piece. They have used ANOVA analysis as research methodology for finding out different outputs like MRR, EWR, SR with the help of different inputs Gap voltage ,peak Current, and Pulse on time, pulse off time, pulse duration. As a result they found that all values of pulse duration the material removal rate increases as pulse current is increased. This is due to that peak current increased the discharge energy is increased and erode more material from the work piece. MRR in decreased with pulse on time at low discharge current. As a peak current increases, the TWR increases and the impact of pulse on time on tool wear is contrary of peak current, as a pulse on time increases the tool wear rate is decrease and the TWR reaches minimum at 200 µ sec spark on time for all values of peak amperes. Surface roughness increase linearly with peak current for different pulse on time, SR is increases as pulse duration is increased.

Arjun Kumar, R.S.Jadoun , Sushil Kumar Choudhary had work on Investigations on tool wear rate of AISI D2 Die steel in EDM .They used Copper as a electrode. The study has been done by using Taguchi's method L9 orthogonal array and analyzed using minitab software under different condition parameter like pulse on-time, pulse off-time, voltage, current. The effect of above mentioned parameters upon machining Performance characteristics such as Tool wear rate (TWR) are studied and investigated on the electric discharge machine. It was find that the tool wear rate is linearly vary with the processparameters. MRR with respect to Toff, it is decrease rapidly initially and after that it increase. TWR also decrease with respect to the current. Gap voltage also less contribution to tool wear, at initial level of the voltage the TWR increase slightly and after that it is falls down.

P. Janmanee, A.Muttamara had worked on performance of difference electrode materials in EDM of Tungsten carbide using electrodes such as Graphite , Copper Graphite, Copper tungsten & used Tungsten carbide as a work piece. They have used ANOVA analysis as research methodology for finding out different outputs like MRR, EWR, SR with the help of different inputs like Pulse off time, Open circuit voltage, Electrode polarity (Negative), Discharge Current, and Pulse on time. As a result they found that Negative polarity graphite electrode has the most MRR 11% & both powder electrodes give the better MRR and EWR more than solid electrode & increased current have influence to increasing of MRR.

Pradhan studied that Electrical discharge machining is based on material removal rate (MRR), tool wear rate (TWR), relative wear ratio (RWR) and surface roughness (SR). EDM machining process performance measures that affect important parameters of the discharging current, Ton time, pulse off time, gap, and are duty cycle. A considerable amount of work MRR, TWR, RWR based on EDM performance measurement, and different materials have been studied by researchers at the SR.

Mohd Amari Lajis Investigated using the Taguchi method using tungsten carbide ceramic cutting electrical discharge machining (EDM) with a graphite electrode. Taguchi method to prepare the experimental layout, machining characteristics to analyze the impact of each parameter, and thus the peak current, voltage, pulse duration and interval time as the optimal choice for each parameter to predict EDM is used. It has been found that these parameters metal removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR) as such have a significant effect on the machining characteristics. Taguchi method analysis shows that, in general, peak current significantly, EWR and SR affects the pulse duration mainly affects the MRR.

K.S.Banker, A.S.Oza, R.B.Dave had worked on the Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) is measured and recorded for detailed analysis. Different electrode materials viz. Aluminium, Brass, Copper and work piece material as AISI 304L have been employed for the set of experiments. The dielectric used is Kerosene diluted with water. Copper is found to be having the highest MRR, (As shown in graph.1) followed by Aluminium and finally Brass. The TWR of Brass is very high (pick point in the graph.1), followed by Copper and Aluminium has the least. The tool-work piece surface roughness measure indicates that Aluminium has the highest SR followed by Brass and then Copper. Hence we find that Brass has got good surface finish properties but owing to its cavity formations, high TWR and other defects, is not favourable for EDM process. Aluminium and Copper is found to be equivalent to each other in terms of MRR, TWR and SR. They are also similar in terms of availability and cost. While carrying out experiments, we have found the carbon deposition on the tool-work piece interface is a menace and hence needs to be cleaned with the help of a sand paper at regular intervals.

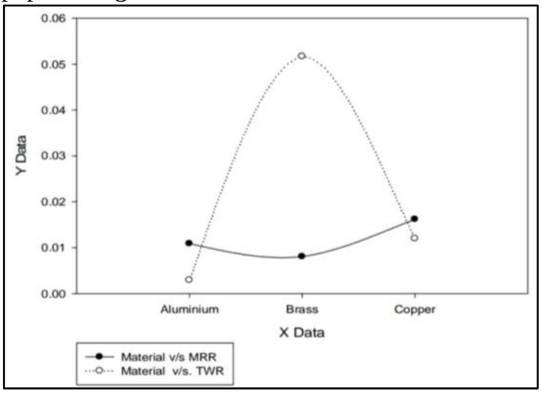

Fig. 2: Material Vs MRR and Material Vs TWR

M.S.Reza, Khairul Anuar, S. H. Tomadi, M.A. Hassan, W.S. W. Harun, M.A. Azmir, Z. Hamedon have been studied Effects of machining characteristics on electrical discharge machining using different types of electrode materials. They used three types of material that are copper, aluminium and brass as a electrode and tool steel XW42 as a work piece material. They found that the higher material removal rate (MRR) is by using electrode copper followed by aluminium and brass. While, for electrode wear ratio (EWR) the higher value is brass followed by aluminium and copper. Finally conclude that the machining characteristics in machining process of electric discharge machine (EDM) influence the machining performance. The higher material removal rate (MRR) will result in better machining performance rate. The higher material removal rate (MRR) obtained is come from electrode copper that is 0.0098 g/min followed by aluminium (0.00419g/min) and brass (0.00109 g/min). The less electrode wear ratio (EWR) will increase the machining performance. And the best selection electrode for electrode wear ratio (EWR) is copper (0.023) followed by aluminium (0.026) and brass (2.187). The best selection of electrode in machining tool steels is copper because it has high material removal rate (MRR) and less electrode wear ratio (EWR).

Can Ogun, S. Akaslan Had Worked On The Effect of Machining Parameters On Tool Electrode Edge Wear and Machining Performance In Electric Discharge Machining. And Found That The Wrr And Twr Are Increased With The Increasing Discharge Current. The Increase In Twr With Pulse Time Is Evident At Low Pulse Time Settings. At High Pulse Time Settings, A Slight Reduction In Twr Is Observed. The Wrr Is Increased By Increasing Pulse Time. The Increasing Dielectric Pressure Slightly Improves The Wrr, Especially At High Current Settings. The Results Are Attributed To The Increasing Removal Effect (Energy)Of Discharge Pulses From Both Tool Electrode And Work Piece With Increasing Pulse Time, Discharge Power And Dielectric Pressure. The Rw Is Reduced With Increasing Pulse Time. A Slight Increase In Rw Is Observed With Increasing Current. The Variation of Twr and Rw with the Dielectric Flushing Pressure Is Insignificant For the High Pressure (Above I Bar) Values.

Shivendra Tiwari have investigated optimization of electro discharge machining with respect to tool wear rate. They used copper as electrode material and mild steel as a work piece material. They considered parameters are peak current, pulse on-time, pulse off-time and control the tool wear. They were taken peak current as 3A because at the higher value of arcing and low values of current the MRR was very low. Pulse on-time was taken as 50 micro second and 300 micro second. Gap voltage was taken as 50V to 75 V. Finally they found out that minimum value of tool wear rate of copper electrode material.

Hitesh.B.Prajapati, V.A.Patel, Hiren.R.Prajapati investigated work on different electrode materials in electro discharge machining for Material removal rate and surface roughness. They used Graphite, copper and Brass as a electrode material and EN-19 used as a work piece material. Peak current, pulse on time and pulse off-time considered as a input parameter. They conclude that graphite gives higher MRR other two Electrodes. Brass gives good surface finishing other two Electrodes. Get more surface roughness at higher value of current. At lower current we can be achieved higher surface finish. Powder electrode gives the better MRR than solid electrode.

Shankar Singh, S. Maheshwari, P.C.Pandey determines the machining settings like pulse current in EDM machining of EN-31 tool steel using Copper, Copper tungsten, Brass and Aluminium electrodes. They were investigate the effects on machining parameters MRR, TWR, Diameteral overcut and SR. Finally they conclude that copper and aluminium electrodes produced diameteral overcut on EN-31 is comparatively low. Copper and Copper tungsten gives comparatively low electrode wear. Aluminium electrode also gives good results while brass wears the most.

Vishal J Nadpara, Ashok Choudhary has done experiment performed on AISI D3 tool steel using graphite electrode of 10 mm diameter. The process parameters were took on the basis of Taguchi method. They considered input parameters such as Current, Voltage, Pulse on-time, Pulse off-time. In this experiment they have taken total 27 readings on the graphite electrode. Finally conclude that the Material removal rate (MRR) affected by Current(Ip). And Duty cycle (t) has least effect on it. The electrode wear rate (EWR) is lower by peak current (Ip). Gap voltage is less on EWR.

V. Conclusion

Literature reveals findings on Electro Discharge Machining of various materials. Most of the work is reported to study the parameters like Peak current, Pulse on time, pulse off time and voltage to find out Surface roughness, Material removal rate (MRR) and Tool wear ratio (TWR) using different types of tools and with the help of design of experiments and statistical optimization techniques. Parameters like discharge current, gape voltage, pulse on time, pulse off time in electro discharge machining process directly or indirectly.

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