

Comparative study of effect of tool materials in EDM process

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Abstract. Electro Discharge Machine (EDM) has shown tremendous application in machining of various electrically conducting materials precisely and accurately. Micro level precision is attained in EDM with hard alloys of steel. In the current paper EDM is carried out on copper plates with copper and stainless steel tool wires. A comparative study based on the effect of tool materials in machining copper plate is conducted. Stainless steel as tool materials has found to better in terms of higher material removal rate and lower tool wear in EDM process. A multi objective optimisation is carried out to analyse the best parameter combination with each tool material. Microscopic images are taken to study the quality of the micro holes machined in each cases.

Keywords: EDM, grey relational analysis, duty factor

1. Introduction

Going with the improvement of mechanical industry, the requests for compound materials having high hardness, sturdiness and effect resistance are expanding. All things considered, such materials are hard to be machined by customary machining strategies. Consequently, non-conventional machining strategies including electrochemical machining, ultrasonic machining, Electro Discharge Machine (EDM) and so on are connected to machine such hard to machine materials. Moreover, EDM is fit for delivering a fine, exact, erosion and wear safe surface. Customary machining system is regularly in view of the material evacuation utilizing instrument material harder than the work material and can't machine them financially. An EDM depends on the disintegrating impact of an electric spark on both the cathodes utilized. EDM really is a procedure of using the expulsion marvel of electrical-release in dielectric. EDM is a most fundamental non-traditional machining process, where material is evacuated by warm vitality of spark happening by methods for rehased arrangements of electrical discharges between the little crevice of a terminal and a work piece. EDM is normally utilized for machining of electrically conductive hard metals and combinations in car, aviation and pass on making businesses

2. Literature review

J. Kozak [1] discovered that setting and keeping up a little yet stable hole estimate in PECMM is critical to accomplish a superior dimensional exactness control. The suitable least hole measure, notwithstanding, is restricted by entomb cathode crevice conditions, for example, electrolyte bubbling. A



model created to appraise the base crevice estimate uncovers that a shorter pulse on-time would permit a littler least hole measure without electrolyte bubbling. Test examinations affirmed the hypothetical outcomes, which licenses to suggest numerical models and programming for re-enactment of PECM for useful applications.

Vinod Yadav et al [2] performed numerical simulations to anticipate thermal stresses in HSS workpiece by building up a limited component based code. The outcomes acquired serve to light up the harming way of thermal stress as they create amid EDM. It is observed that after one spark, generous compressive and tractable burdens create in a thin layer around the spark area. It is additionally found that the thermal stress surpass the yield quality of the workpiece generally in a greatly thin zone close to the spark. The results illustrated the damaging nature of thermal stresses during EDM process. W Murray et al [3] determined the effects of debris in EDM. Debris was imagined using SEM and TEM techniques, revealing particle sizes and other properties of debris.

S.L.Chen, et.al [4] stated about Influence of kerosene and distilled water as dielectrics on the electric discharge machining characteristics of Ti-6Al-4V alloy under various machining condtions. Leera Raju et.al [5] carried out an extensive literature study in their journal “A state of the art review on μ -EDM” to give a complete description on μ -EDM process, its requirements, performance and applications. The experimental setups and its subsystems, experimental studies and optimization methods, generated micro feature and various applications are described in this journal.

Wang et.al [6] experimentally investigated a wear-resistant electrode for micro-EDM. The results proved that Cu-ZrB₂ composite (copper-zirconium Diboride) coated electrodes have better wear resistance than pure copper electrodes. They also found that it is feasible to use the wear compensation method on the basis of the difference between the wear ratio of matrix and that of coating material to maintain electrode shape precision. S.K.Choudhury et.al [7] conducted experiments using air as the dielectric medium to study the effect of gap voltage, discharge current, pulse-on time, duty factor, air pressure and spindle speed on material removal rate (MRR), surface roughness (Ra) and tool wear rate (TWR).

In the current study an EDM setup is developed and micro holes machined in copper workpiece with different tools. The input variable parameters are Voltage, Frequency and Duty factor. Taguchi method is applied to create an L9 orthogonal array of input variables using the Design of Experiments (DOE). The effect of the variable parameters mentioned above upon machining characteristics such as Material Removal Rate (MRR), and Tool Wear Rate (TWR) is studied. A multi objective optimization of parameters is carried out using Grey Relational Analysis (GRA)

3. Experimental setup

The experimental setup for EDM consists of different subsystems. Fig 1 shows the experimental setup with DC power supply and function generator. The deionized water is used as dielectric and it provides insulation against premature discharging, cools the machined area, and flush away heat, damaged dielectric and the EDM chips and debris



Fig.1 Overall machine setup

The workpiece used is copper and is cut into small square pieces and with a thickness 0.5 mm. Copper of 1 mm diameter and stainless steel tool of 0.5mm diameter are taken as tools.

4. Experimental investigation

The experiment is carried out in order to get maximum material removal rate with minimum tool wear. In this experiment the input parameters such as voltage, frequency and duty factor is varied. In the output of the experiment, the material removal rate and tool wear rate are examined. The maximum material removal rate and minimum tool wear rate can be found at a particular combination of voltage, frequency and duty factor, and can be optimized using Taguchi method. Design of experiment is a powerful analysis tool for modelling and analysing the influence of control factors on performance output. An experimental plan based on Taguchi orthogonal array (L_9) was chosen. Two different workpieces and tool are used during the machining. Two sets of experiments were planned to be carried out:

1. Set of experiments with copper as workpiece and copper rod as tool (diameter of 1mm)
2. Set of experiments with as copper as workpiece and stainless steel as tool (diameter of 0.5 mm.)

The experiments were conducted with varying tool diameters in order to obtain holes in the micro-level. The experiments were conducted with DI water as the dielectric fluid. The machining parameters selected on the basis of trial machining results. The machining parameters selected for the experimentation are Voltage (V), Frequency (KHz), Duty factor (%). The three levels for each parameter are as follows:

4.1 L_9 Experiments with copper tool and copper work piece

Based on the levels of the process parameters selected, the experimental plan is developed using L_9 orthogonal array with output responses is given in Table 1.

Table 1. Experimental layout plan of L_9 orthogonal array

EX. NO	VOLTAGE (V)	FREQUENCY (kHz)	DUTYFACTOR (%)	MATERIAL REMOVAL RATE (mg/m)	TOOL WEAR RATE (mg/m)
1	40	2	60	0.575	0.212
2	40	4	70	0.589	0.233
3	40	6	80	0.501	0.201
4	45	2	70	0.616	0.225
5	45	4	80	0.582	0.214
6	45	6	60	0.683	0.298
7	50	2	80	0.654	0.284
8	50	4	60	0.710	0.327
9	50	6	70	0.791	0.341

4.2 L_9 Experiments with stainless steel tool and copper workpiece

In experiment set 2 the workpiece used is copper plate of 0.5mm thick and tool used is stainless steel rod of 0.5mm diameter. DI water is used as Di electric fluid. The experimental results obtained are given in Table 2.

Table 2: Experimental observation of experiment set 2

EX NO	VOLTAGE (V)	FREQUENCY (kHz)	DUTYFACTOR (%)	MATERIAL REMOVAL RATE (mg/min)	TOOL WEAR RATE (mg/min)
1	40	2	60	0.541	0.202
2	40	4	70	0.582	0.141
3	40	6	80	0.521	0.143
4	45	2	70	0.631	0.167
5	45	4	80	0.688	0.181
6	45	6	60	0.701	0.189
7	50	2	80	0.748	0.221
8	50	4	60	0.765	0.269
9	50	6	70	0.795	0.295

5. Results and discussions

Material removal rate (MRR) and Tool wear rate (TWR) have been calculated for each of the experiments based on the experimental observations. In the present work, multi-objective optimization of the EDM process has been carried out by considering maximization of MRR and minimization of TWR as two distinct objectives in both experiments. The Grey relational analysis is used to optimize the machining parameters with multiple performance characteristics such as Material Removal Rate (MRR) and Tool Wear Rate (TWR).

5.1 Experiment set 1

In experiment set 1 the workpiece used is copper plate of 0.5mm thick and tool used is copper rod of 1mm diameter. DI water is used as Di electric fluid. Based on the experimental observations the signal to noise ratios for MRR and ROC has been calculated. The normalised signal to noise ratios and deviation sequences has been calculated as per the equations in grey relational analysis. Also the grey relational coefficient and grey relational grade has been calculated and ranked according to priority in each experimental set.

Table 3: Ranking for grades in experiment set 1

EX.NO	GRG	RANK
1	0.579	3
2	0.515	7
3	0.599	2
4	0.478	9
5	0.576	4
6	0.524	6
7	0.499	8
8	0.547	5
9	0.733	1

A response table for parameter voltage, frequency and duty factor

Table 4: Response table of parameters for experiment set 1

Voltage	1.556	1.63	1.856
Frequency	1.693	1.578	1.779
Duty factor	1.65	1.726	1.908

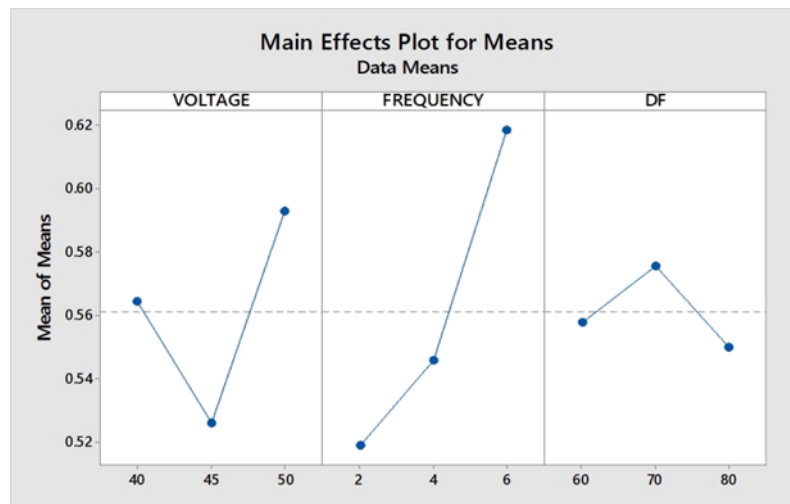


Fig.2 Optimum values for set 1

A confirmation test is conducted based on the best parameter combination obtained from multi-objective optimisation with voltage = 50V, frequency=6KHz, duty factor = 70%. The maximum MRR obtained from the experiment is 0.791 mg/min with minimum TWR 0.341 mg/min. The MRR obtained from confirmation test is found as 0.797mg/min and TWR of 0.278 mg/min which is in agreement with experimental result.

The ranking table for the experiment with stainless steel as tool is as follows:

Table 5: Ranking for grades in experiment set 2

EX.NO	GRG	RANK
1	0.203	7
2	0.187	8
3	0.167	9
4	0.221	6
5	0.263	5
6	0.278	4
7	0.344	3
8	0.413	2
9	0.5	1

A response table is calculated and is given below.

A confirmation test is conducted with parameter combination of voltage = 50V, frequency=6KHz and duty factor = 70%. The MRR obtained from L9 set= 0.795mg/min TWR obtained from L9 set =0.295mg/min. Also the MRR obtained from confirmation test= 0.801 mg/min TWR obtained from

confirmation test = 0.241 mg/min. By comparing first two experiments it is noted that the tool wear rate is less in the case of stainless steel tool than the copper tool while machining copper workpiece.

Table 6: Responses of experiment set 2

Voltage	0.768	0.863	0.945
Frequency	0.557	0.651	1.257
Duty Factor	0.894	0.908	0.93

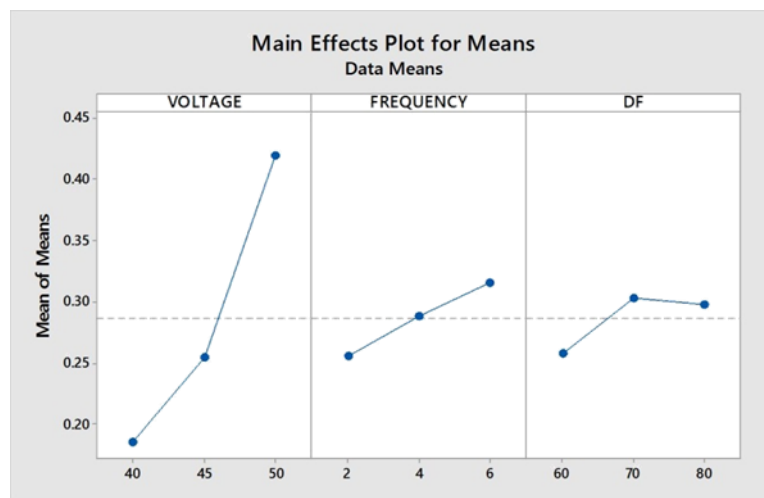
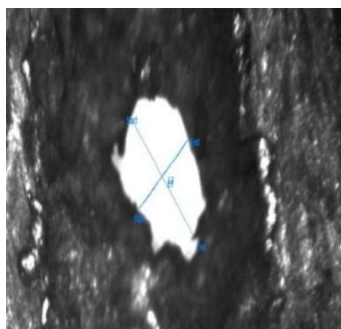


Fig.3 Optimum values of experimental set 2

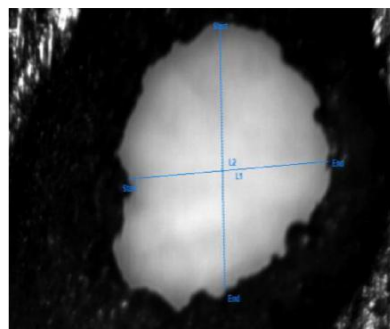
5.2. Microscopic images

The microscopic images are taken for copper workpiece with stainless steel tool and are given below.

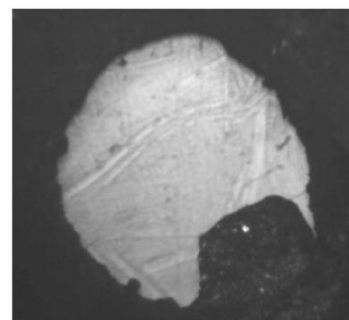
a) Microscopic Images of Workpieces for Voltage 40 V



Workpiece 1
Voltage= 40 V
Frequency = 2 kHz
Duty factor= 60



Workpiece 2
Voltage= 40 V
Frequency = 4 kHz
Duty factor= 70

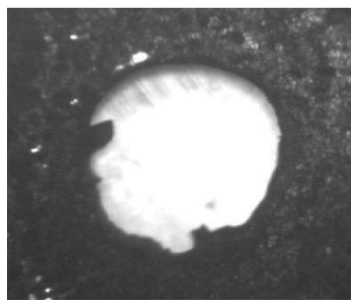


Workpiece 3
Voltage= 40 V
Frequency = 6 kHz
Duty factor= 80

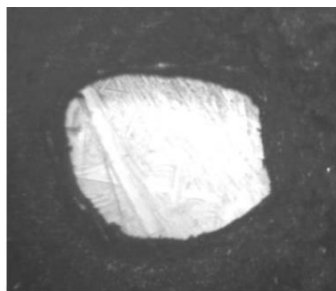
Fig.4 Microscopic Images of samples at 40 V

As the voltage is lower, energy of the spark generated is also less so that the material removal rate is less compared to higher voltages. Because of this the hole is not completely machined in fixed machining time.

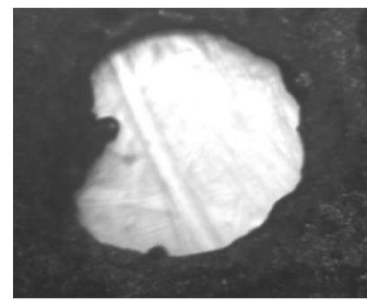
b) Microscopic Images Of Workpieces for Voltage 45 V



Workpiece 4
Voltage= 45 V
Frequency = 2 kHz
Duty factor= 70



Workpiece 5
Voltage= 45 V
Frequency = 4 kHz
Duty factor= 80

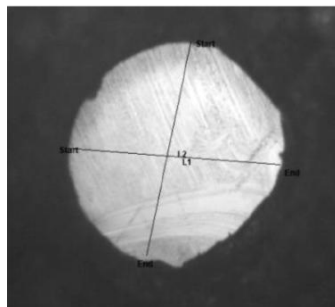


Workpiece 6
Voltage= 45 V
Frequency = 6 kHz
Duty factor= 60

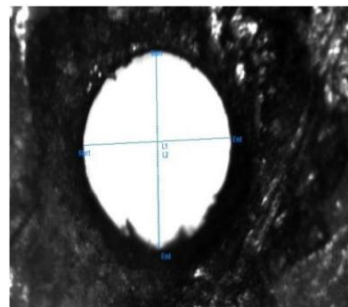
Fig.5 Microscopic Images of samples at 45 V

Here the voltage is increased by 5V and the material removal rate is also gradually increased. This leads to the complete drilling of holes but the hole is irregular and at duty factor 70 micro-hole is much better than others.

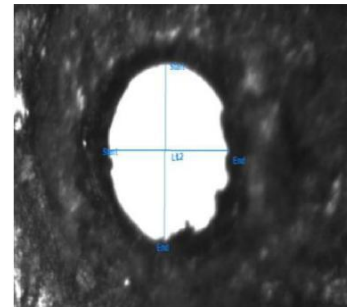
c) Microscopic Images Of Workpieces for Voltage 50 V



Workpiece 7
Voltage= 50 V
Frequency = 2 kHz
Duty factor= 80



Workpiece 8
Voltage= 50 V
Frequency = 4 kHz
Duty factor= 60



Workpiece 9
Voltage = 50 V
Frequency = 6 kHz
Duty factor =70

Fig.6 Microscopic Images of samples at 50 V

Here the voltage is increased to 50 V and the material removal rate is also gradually increased. This leads to the complete drilling of holes with regular shapes and at duty factor 60 micro-hole is much better than others. From the microscopic images it is concluded that the MRR get increased with higher voltage and regular holes are attained at moderate duty factors. ROC get reduced at lower DF due to more cooling time at lower DF.

6. Conclusion

In this investigation, development of a micro EDM setup for machining micro hole is discussed. Experiments were conducted with different tools on copper workpiece combination. During the experiment the Di-electric medium used is de-ionised water. The process parameters selected for experiments are voltage (V), Frequency (KHz) and Duty factor (%). Machining was conducted based on L9 orthogonal array for experiments. MRR and TWR were taken as the output parameters for all

three experiment sets. Multi-objective optimisation using grey relational analysis was carried out in order to obtain the best parametric combination. Based on the optimised parametric conditions, confirmation tests have been carried out. The best parameter combination obtained for experiments done on copper workpiece with copper tool are Voltage of 50 V, 6 KHz Frequency and 70% Duty factor. After that conformation tests are carried out with the optimum parameters obtained and the test results provide $MRR = 0.797 \text{ mg/min}$ and $TWR = 0.278 \text{ mg/min}$. The best parameter combination obtained for experiments done on copper workpiece with Stainless steel tool are Voltage of 50 V, 6KHz Frequency and 70% Duty factor. Conformation tests are carried out with the optimum parameters obtained and the test results provide $MRR = 0.801 \text{ mg/min}$ and $TWR = 0.241 \text{ mg/min}$. By comparing these two set of experiments it is noted that stainless steel tool is better than copper tool for the micro hole machining in the copper workpiece. The material removal rate is almost similar in two cases and the tool wear rate is less in the case of stainless steel tool compared to copper workpiece. Tool wear is noted that less in case of stainless steel tool than copper tool.

Voltage and Frequency are the energy factors, during the experiments. It is noted that as voltage increases material removal rate also increases. This is due to increase in discharge energy when voltage increases more discharge current will pass through the gap and it causes more material removal. But the voltage is at very high value is not preferable for the machining because in high voltage spark may change to arc so proper machining is not happening. If off time is too less it may affect the removal of debris from the gap and proper machining will not occurs. During the experiments it is noted that for stainless steel workpiece high voltage applied is 60V but the maximum MRR obtained at 55V this may due to at 60V sparking action is not properly done. At 60V arcing may occur. Duty factor is the other parameter; from results it is clear that 70% DF is better. 70% DF means 70% ON Time of pulse and 30% OFF Time.

References

- [1] J. Kozak (2000) Thermal models of pulse electrochemical machining, Institute of Manufacturing Technology, Warsaw University of Technology, Vol. 222, 650–663
- [2] V. Yadav and K. Jadav, (2002) Thermal modelling of EDM, International Journal of Machine Tools and Manufacturing Vol. 42, 877–888.
- [3] Murray, J.W., Sun, J., Patil, D.V., Wood, T.A., Clare, A.T. (2015), Physical and Electrical Characteristics of EDM Debris. Journal of Materials Processing Technology 10, 10–16.
- [4] S L Chen, B H Yan, F Y Huang, (1999) “ Influence of kerosene and distilled water as dielectrics on the electric discharge machining characteristics of Ti-6Al-4V”, Journal of materials processing technology 87, 107–111.
- [5] Leera raju, Somashekhar S Hiremath, (2016) A state of art review on micro electro discharge machining, Global colloquium in recent advancement and effectual researches in engineering science and technology Rearest 2016 Procedia Technology 25 (2016) 1281.
- [6] Weng, F.T. (2001), Micro-hole machining of copper using the electro discharge machining process with a tungsten carbide electrode compared with a copper electrode, International Journal of Advanced Manufacturing Technology, 17(10), pp715–719.
- [7] Sourabh K. Saha, S.K. Choudhury “Experimental investigation and empirical modeling of the dry electric discharge machining process” Thesis reports, Department of Mechanical Engineering, Indian Institute of Technology Kanpur, Kanpur, India.