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Optimization of Process parameters on EN-24 Alloy steel using Taguchi method in Die Sinking Electro-Discharge Machining

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ABSTRACT
In the manufacturing sector, electric discharge machining (EDM) is used because of its unique machining features and high accuracy which can't be done by other traditional machines. The purpose of this paper is to analyze the optimum machining parameter, to curtail the machining time with respect to high material removal rate (MRR) and low tool wear ratio (TWR) by varying the parameters like current, pulse on time (Ton) and varying electrode material. By conducting several dry runs using Taguchi technique of L9 orthogonal array (OA), optimized parameters were found and the parameter contribution for MRR and TWR were found.

***Keywords*:** EDM, Taguchi, Tool wear rate, electrodes , Materials for electrodes

List of symbols

EDM : Electric discharge machining

T_{on} :Pulse on time (µs)

I_p : Peak current

EWR : Electrode wear rate (mm3/min)

MRR : Material removal rate

TWR: Tool wear rate

SR : Surface roughness

1. INTRODUCTION

Electric discharge machining (EDM) is a non-traditional machining process which is based on the thermal erosion of electrically conductive work piece and tool electrodes. Electrical discharge machining has become one of the most important production technologies to manufacture very accurate three-dimensional complex components on any electrically conductive material [1]. Examples include precision machining of hardened steels, carbides and ceramic materials [2]. The product cost manufactured by the EDM process mainly depends on the tooling cost, which comprises the cost of tool material, tool fabrication, and tool maintenance. The properties of tool

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material affect the machining performance parameters like MRR, TWR, and surface roughness. They are also affected by the tool geometry, tool fabrication method, and the way by which both tools and work piece interact with each other. In the EDM process, tool wear is difficult to avoid and high TWR reduces the accuracy of the machined parts. Therefore, to obtain the desired accuracy it is necessary to calculate TWR and provide wear compensation. The thermo-physical properties of the electrode, such as thermal and electrical conductivity, thermal expansion and heat needed to vaporize from room temperature, melting and boiling temperature have a considerable influence on the EDM process performance in terms of material removal rate, electrode wear and surface integrity of the work piece [3]

Since the process parameters are related strongly to the machined material, most of the published literature focuses on investigating the effect of EDM process parameters for machining a specific alloy. Lin et al (2002) described that electrode (EWR) and MRR can be improved by optimizing the EDM process parameters using Taguchi techniques with Fuzzy logics[4]. Torres, A. et al.examined the impact of process parameters; electric current (I_p), pulse on-time (T_{on}), duty cycle and electrode polarity on MRR, EWR% and SR in EDM of INCONEL 600 Alloy with copper as the electrode material, the dielectric liquid used was mineral oil with a flash point of 82 C. They found that positive polarity leads to higher MRR though negative polarity leads to lower SR values [5]. Yan Cherng Lin et al. [6] studied the impact of process parameters, including, I_p, T_{on} and gap voltage on MRR, EWR and SR in EDM of SKH 57 high speed steel with copper electrode material. Their study demonstrated that the MRR increased with the I_p, and the maximum values were achieved at T_{on} of around 100 µs, as the Ton increased further, the MRR was reduced. Raj, Sumit, et al. [7] observed that I_p and pulse off-time are the most significant parameters for MRR. M.M. Bahgat,et al (2019) analysed the Influence of process parameters in electrical discharge machining on H13 die steel[8]

2 EXPERIMENTAL SETUP & MATERIALS

In this work, the experiments were conducted on Model: TOOLCRAFT SPARK EROSION MACHINE G60 electrical discharge machining with Copper , Brass and graphite electrode. In this experiment EN 24 is chosen for conducting the experiment. EN24 is a quality high carbon alloy steel which offers a high degree of hardness with compressive strength and abrasion resistance, EN24 steel is a potential member of the automobile industry, and achieving dimensional accuracy with outstanding surface characteristics is a challenging task while machining this alloy.

In this experiment graphite, brass and copper electrode rod of 32x18x16 mm^2, Ө 16x13 mm^2, 30x18x8 mm^2 is used. Brass is a metal alloy made from copper and zinc has some very specific properties, which make it one of the most widely used alloys. There are countless possible uses of brass. Especially due to its versatility .It is used in many industrial product.

Copper has the best electrical conductivity of any metal, except silver. A good electrical conductivity is the same as a small electrical resistance. Graphite is the second most common electrode material for EDM, due to its thermal and electrical properties, allied with good machinability.

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Fig.1 Copper electrode

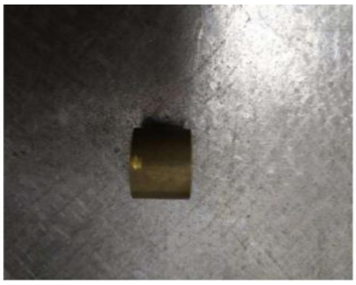

Fig.2 Brass electrode

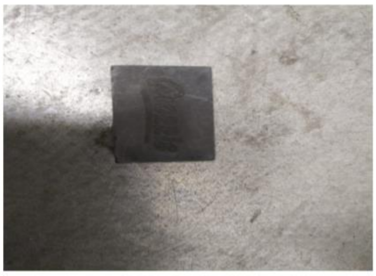

Fig.3 Graphite electrode

The machine is computer controlled consisting of a servo motor with servo feed mechanism, a magnetic worktable with dielectric supply system. The machine has 10 current setting ranges from 3 to 27 amps with pulse on time (T_{on}) and pulse off time (T_{off}) settings on board. The work piece is EN24 tool steel of 25mm in diameter and 30mm in length, which has a hardness of 193BHN and HRC = 45, density = 7850 kg/m3, thermal conductivity of 25 w/mk. For lubrication and cooling purposes, EDM oil with specific gravity of 0.763 was used as a dielectric medium. The machining has been done with straight polarity. The trials with respect to levels and factors are calculated by Taguchi's technique.

Fig. 4_5 EDM die sinking machine

After completing all the trials using the data obtained from MINI TAB software of L9 OA, the nominal MRR and best TWR has been calculated using the following formulae,

MRR = (Wb - Wa / ρ .t) mm^3 / min

Where Wa= weight of the work piece after machining in 'grams'

Where Wb= weight of the work piece before machining in 'grams' T= time taken in 'sec'

ρ = the density of EN 24 (8.08×10^{-3} g/mm^3)

EWR = (Eb – Ea / ρ. t) mm^3 / min

where WTA= weight of the tool after machining in 'grams' where WTB= weight of the tool before machining in 'grams' T= time taken in 'sec', ρ = the density of electrode material

Electrode wear ratio (%) =(Volume of material removed from electrode) /(Volume of material removed from work piece)X100

Fig. 6 : EN-24 work piece before machining (30x28x28 mm^2)

Variables	Setup value
Electrode material	Graphite, Copper, Brass
Dielectric fluid	Kerosene
Flushing pressure (kgf/cm^2)	3.0
Gap Voltage (V)	45
Peak current (A).	2, 6, 14
Spark gap (mm)	0.05-0.25
Duty cycle rate	50%
Pulse on-time (µs)	50, 150, 500
Electrode polarity	Positive
Depth of cut	0.1 mm

Table 1. Process parameters of EDM

Properties	Copper	Brass	Graphite
Melting point (C)	1083	1030	3650
Density kg/m^3	8930	8860	2250
Thermal conductivity(W/mk)	385	233	25
Electrical resistivity(µΩ cm)	1.7	3.18	6000

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Table 2. Typical room temp mechanical properties of the electrode materials [9][10][11]

	C	SI	P	Mo	S	Mn	Ni	Cr
Minimum	0.36	0.1	-	0.20	-	0.45	1.31	1.01
maximum	0.44	0.35	0.35	0.35	0.04	0.70	1.70	1.40

Table 3: Chemical composition of EN-24 by weight % [12]

3. Taguchi design and Experimentation

The conventional methods of experimental designs require a series of experiments. It utilizes all possible combinations of parameters to analyse the control factors effect on experimental data. As well it takes into consideration all possible combinations to study any possible interaction within control factors. Taguchi ensures cost reduction and identifies significant factors in comparatively lesser time. It is effective in robust design and minimizing noise. Unlike conventional method, Taguchi utilizes a completely different approach. It reduces the number of experiments significantly, with the use of orthogonal arrays. These arrays are combinations of control factors, which evaluates the contribution of factors and assess the best combination of parameters for desired results. The method is based on the signal-to-noise (S/N) ratio. It is the ratio of desired signal with respect to the noise in the background. The higher the ratio, the less is the contribution of noise. Taguchi method identifies the best combination of parameters by the value of S/N ratio. For our case Material removal rate, 'larger the better' types of performance characteristics is used and for Electrode wear rate 'Smaller the better' type is used for optimisation of process parameters.

Three operating parameters Electrode material, Peak current (I_p) and Pulse on time are selected for optimization. Each parameter is set at three levels as shown in Table 4. In order to limit the number of experiments for optimization, Taguchi method was utilized. And combination is set according to L9 orthogonal array for 3 parameters at 3 levels.

Electrode material	**Peak Current (I_p)(Ampere)**	**Pulse on time (t) (µs)**
Graphite	2	50
Copper	6	150
Brass	14	200

Table 4. Processing parameters for EDM operation.

In summary, the complex method of Taguchi can be summarized in the following steps

1. Identifying control factors and set their number of levels.
2. Evaluate the response function.
3. Based on the number of control factors and levels, select an appropriate orthogonal array (L9) and assign the control factors, run the experiments.
4. Evaluate the data generated via Taguchi and ANOVA analysis.
5. The effect of control factors on response function is evaluated.

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4 RESULTS AND DISCUSSION

ANOVA analysis is being performed on experimental results for investigating the contribution of every control factors using MINI TAB.0 version. The two output parameters M.R.R and E.W.R were adopted and measured during Die sinking EDM of EN 24 steel. Table 5 gives the combinations of experimental machining parameters and parameter levels in the L9. This table also gives the S/N ratio for each one.

Experiment no.	Electrode material	Peak current I_p	Pulse on time (µs)	E.W.R (mm^3 /min)	M.R.R (mm^3 /min)	Machining time (min)	EWR (%)	S/N ratio MRR (dB)	S/N Ratio EWR (dB)
1	GRAPHITE	2	50	0.987	3.149	9.00	31.36	9.9635	-29.9275
2	GRAPHITE	6	150	5.925	9.488	3.00	62.44	19.5435	-35.9093
3	GRAPHITE	14	200	14.379	17.520	1.80	82.07	24.8707	-38.2837
4	COPPER	2	150	1.119	3.960	2.00	28.25	11.9539	-29.0204
5	COPPER	6	200	1.866	16.831	1.50	11.08	24.5222	-20.8908
6	COPPER	14	50	4.479	7.673	1.00	58.37	17.6993	-35.3238
7	BRASS	2	200	0.224	9.683	2.18	2.31	19.7202	-7.2722
8	BRASS	6	50	9.080	21.287	1.00	42.65	26.5623	-32.5984
9	BRASS	14	150	7.894	5.406	3.80	146.02	14.6575	-43.2882

Table 5 : L9 orthogonal array with S/N ratio for the MRR, EWR% & machining time .

4.1 Effect of different factors on E.W.R (%)

EWR v/s electrode material . peak current and pulse on time:

Fig. 7 makes it clear that EWR decreases by increasing pulse on time. EWR increase as I_p increases but up to a certain value which varies from one electrode material to the other. Taguchi method was utilized to analyse the results of response of the machining parameters as indicated by "smaller is better" criteria [13]. Table 6, 7 and Fig. 8 illustrates factors level S/N ratios. From Fig. 8, the optimized value for EWR% is found that Brass electrode at I_p = 2A and Ton = 200 **(µs)**. At this condition, can achieve the highest EWR% obtained for EN 24 steel. Peak current, electrode material, pulse on-time are assigned as rank 1, 2, and 3 respectively according to their larger value of delta as shown in Table 6 & 7. Rank 1 means highest effect factor on EWR.

From table 6, 7 it is clear that Pulse on time has more significant effect on EWR% as compared to peak current.

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Level	electrode	peak current	pulse on time
1	58.62	20.64	44.13
2	32.57	38.72	78.90
3	63.66	95.49	31.82
Delta	31.09	74.85	47.08
Rank	**3**	**1**	**2**

Table 6. Response Table for Means

Level	electrode	peak current	pulse on time
1	-34.71	-22.07	-32.62
2	-28.41	-29.80	-36.07
3	-27.72	-38.97	-22.15
Delta	6.99	16.89	13.92
Rank	**3**	**1**	**2**

Table 7. Response Table for Signal to Noise Ratios

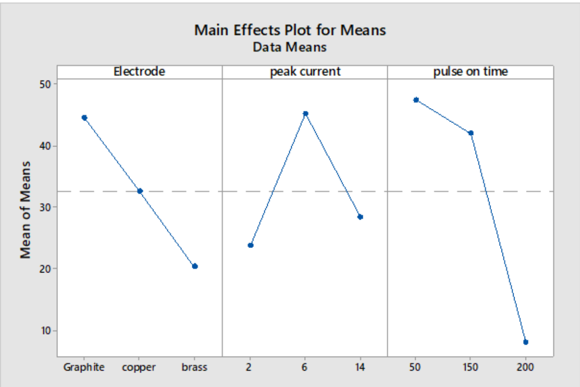

Fig. 7. Main effect plot for means

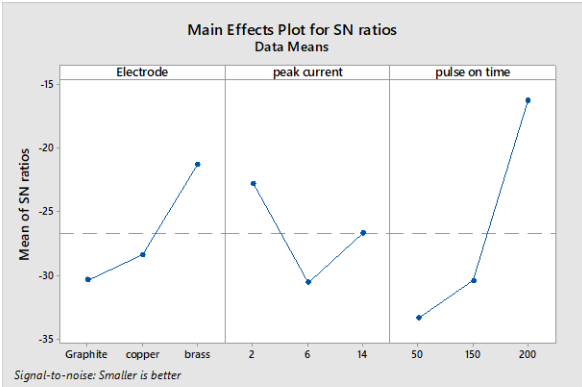

Fig.8 Main effect plot for SN ratios

4.2 Effect of different factors on M.R.R

Level	Electrode	peak current	pulse on time
1	18.13	13.88	18.08
2	18.06	23.54	15.38
3	20.31	19.08	23.04
Delta	2.25	9.66	7.65
Rank	**3**	**1**	**2**

Table 8. Response Table for Means

Level	Electrode	peak current	pulse on time
1	10.052	5.597	10.703
2	9.488	15.869	6.285
3	12.125	10.200	14.678
Delta	2.637	10.271	8.393
Rank	**3**	**1**	**2**

Table 9. Response table for signal to noise ratios

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Fig. 9 illustrate the effect of the electrode material, the I_p, and the T_{on} on MRR. It is clear from Fig. 9 that the MRR increases by increasing the I_p value, up to a certain value which varies from one electrode material to the other. It was found that the MRR decreases by increasing the T_{on}, but it was observed that at the value 150**(µs)** of the T_{on} the MRR began to increase. Taguchi method was utilized to analyse the results of response of the machining parameters as indicated by "larger is better" criteria [13]. Table 8,9 and Fig. 10 illustrates the factors level S/N ratios.

Peak current, electrode material, pulse on-time are assigned as rank 1, 2, and 3 respectively according to their larger value of delta as shown in Table 8 & 9.. Rank 1 means highest effect factor on MRR, rank 2 comes after that and means medium effect factor on MRR, and so on. As clearly seen from table 8 peak current has most significant effect on MRR. From Fig. 10, the optimized value for MRR is found that brass electrode at I_p= 6A and $T_{on=}$ 200 **(µs)**. At this condition, can achieve the highest MRR obtained for EN 24 steel.

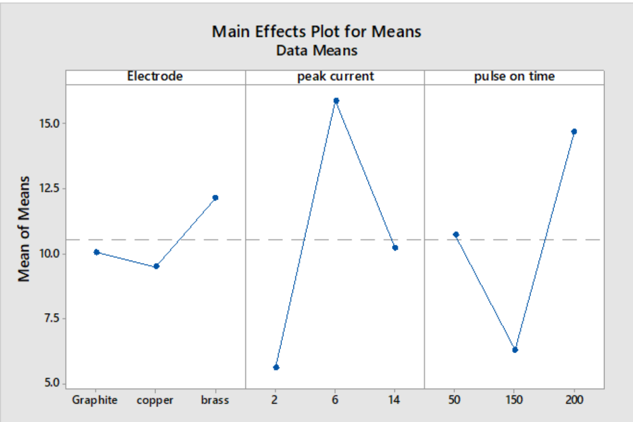

Fig. 9. Main effect plot for means

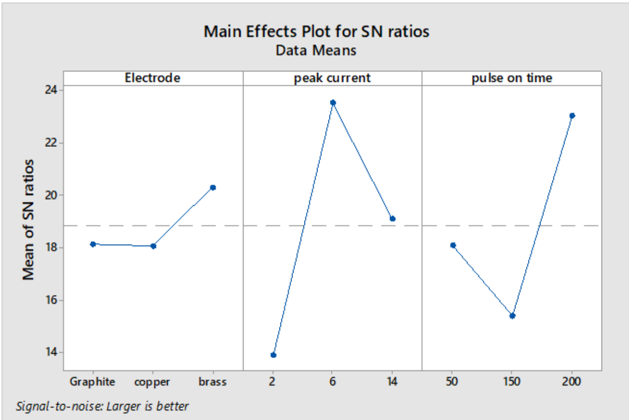

Fig.10 Main effect plot for SN ratios

4.3 The effect of electrode material on the performance measurements

In EDM, the electrical energy is used to generate an electrical spark possessing thermal energy. The work piece material removal is the result of the thermal energy of the spark. The right selection of the electrode material controls the transport of the electrical current to the work piece [14]. Thus, the selection of the electrode material plays a significant role in this process, owing to its thermo-physical properties, though the non-thermal properties are not negligible. The peak current causes the occurrence of a crater after the break down of the open circuit voltage. The occurrence of this phenomenon is only possible when the cathode electrode starts to emit electrons, when the emitted electrons from the cathode collide with the molecules of the dielectric fluid releasing more electrons together with the positive ions. This causes the vaporization of the dielectric fluid and the formation of a high energy plasma channel.

The previous findings suggest that the optimized process parameters should be related to the process type. In EDM manufacturing processes for machining EN 24 steel, the following conditions are recommended for optimal use: (1) brass electrode material with 6A peak current and 200µs pulse on-time, for roughing process in order to increase the MRR and (2) brass electrode with 2A peak current and 200µs pulse on-time, for finishing processes in order to reduce EWR.

4.4 Conclusion & Validation

1. The highest wear ratio was found during machining of EN 24 using a brass electrode. The low thermal conductivity of brass electrodes causes less heat loss, and its low melting point (927 °C) results in fast melting of the electrode material. At the same time, low thermal conductivity of EN 24 results in poor heat absorption, and its high melting temperature (1500°C) causes poor removal of work material. These factors result in the highest wear ratio during machining of EN 24 using a brass electrode.

Result is validated by open literature .Singh et al. [15] used EN-31 tool steel as work piece to analyze the effect of brass electrodes on the performance parameters under different machining conditions. Results reported that brass presented the highest wear when compared to the other electrodes.

2. The highest material removal rate was observed during machining of EN 24 using brass electrodes. Comparatively low thermal conductivity of brass (111 W/mK) as an electrode material does not allow the absorption of much heat energy, and most of the heat is utilized in the removal of material from work piece at a low melting point.

Result is validated by open literature Khan where Saifuddin [16] compared the wear of brass and copper electrodes when EDM machining mild steel and aluminum. It was reported that brass electrodes removed more materials from the work piece than copper.

3. Peak current was found to play a major role in material removal rate and electrode wear ratio and similar was found in a study done by Torres et al. [17] who investigated the EDM performance of graphite electrode with Inconel 600 grade under positive and negative electrode polarity.

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