EXPERIMENTAL INVESTIGATION ON THE EFFECT OF MACHINING PARAMETERS IN ELECTRIC DISCHARGE MACHINING USING AISI 1095-TREATED STEEL

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Abstract: This paper depicts the experimental study of the input parameters of EDM current, pulse on time and pulse off time on output parameters material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). The workpiece materials selected was C100. The copper-tungsten used as tool electrode. After the experiments, MRR, EWR, Roundness, and Ra of the machined surfaces need to be measured in order to evaluate the performance of the EDM process. In order to obtain high MRR, the higher peak current in a range of 0.2A to 128A and pulse duration in a range of 0.5μs to 20μs were used. Experimental results have shown that machining at a highest peak current used of 128A and the highes pulse duration of 20μs used for the experiment yields the highest material removal rate (MRR) with value 57.2mm^3/min, whereas machining at a peak current of 128A and pulse duration of 20μs yields the lowest electrode wear rate (EWR) with value -4.29mm^3/min. The lowest surface roughness (Ra) is 0.8 μm achieved at the lowest peak current used of 0.4A and pulse duration of 2μs.

Key words: electrical discharge machining, machining parameters optimization, surface roughness, tool wear rate, material removal rate.

Nomenclature

C100	Tool steel
EDM	Electric Discharge Machining
EWR (mm^3/min)	electrode wear rate
TWR (mm^3/min)	Tool Wear Rate
MRR (%)	Material Removal Rate
ROC (mm)	Radial over cut
Dw (mm)	Diameter of the workpiece
Dt (mm)	Diameter of the tool
T (min)	Machining time
T_i (g)	weight of tool after machining
T_f(g)	weight of tool before machining
T_{on} (μs)	pulse-t-on
T_{off}(μs)	pulse off time
W_i (g)	weight of workpiece after machining
W_f(g)	weight of workpiece before machining
ρw (g/cm^3)	Density of the material
ρt (g/cm^3)	Density of tool material.
Ra (μm)	Roughness Average
Ip (A)	Discharge current
Round (mm)	Roundness

1. INTRODUCTION

Electroerosion machining (EDM) technology has progressed to one of the main manufacturing processes used in the machining of special shapes, dies, mold cavities for injection and molds to generate complex three-dimensional cavities in many classes of materials in roughing and finishing operations. EDM allows precision machining of hardened steels, alloys, carbides, ceramic materials and many other materials with minimal electrical conductivity, which is too hard or too delicate to be machined by conventional methods, as indicated by Ho and Newman [1] and Ho et al. [2]. In 1940, B. R. Lazarenko and N. I. Lazarenko are initially employed EDM for stock removal which was established as an elementary die-sinking machine [3]. During the EDM process, the material removal rate and the wear rate of the tool, play an important and effective role in industrial performance. Furthermore, these features are generally influenced by EDM parameters such as pulse on time, pulse current, voltage etc., which should be optimized to reach the best conditions [4, 5]. Die sinking EDM technology is used extensively in the machining of special shapes in full-hardened die steel, avoiding the problems of dimensional variability, which are characteristic of post-thermal treatment. The material's melting point, hardness or brittleness does not affect the process and the tool does not have to be harder than the workpiece, as no mechanical contact in during machining and no mechanical force is applied to the workpiece. Moreover, there is no risk of stress distortion because there is no physical contact between the electrode and the workpiece. Since the development of the EDM process by Lazarenko [6], various theories for material removal and surface finishing have been postulated. As reported by König et al. [7], several models, based on electro-mechanical and on thermo-mechanical theories, have been proposed to explain the influence of parameters in the complex phenomena during the EDM process. These two types of theoretical models, like many others, are not conclusive because of the lack of experimental evidence, as referred by Ho and Newman [1]. The choice of a particular tool electrode material (eg, graphite, copper, copper-tungsten,) depends on the material of the workpiecebeing machined. Copper-tungsten electrodes have been widely used for the machining of steel and carbide parts, as studied by Li et al. [8]. AISI 1095 is considered as a difficult material to cut because of its high hardness, as well as its fast curing rate. In addition, a low thermal conductivity of the carbon-based steel results in a heat concentration in the cutting zone, which renders it ineffective to process by conventional machining. Quality C100 is the most popular material of choice for a construction, both economic and ecological have very good mechanical properties such as tensile strength, fatigue resistance, lightness (highest strength/weight ratio), strength to corrosion withstand high temperature [9]. Until today, EDM has successfully used to machine hard materials. By applying latest EDM technology, Regardless of the application, the workpiece may be of any material, no matter how hard, as long as it is electrically conductive, Fonda et al., [10]. However, the main influence in EDM machining will be determined by electrical parameters such a peak current, pulse duration and voltage, material properties of the workpiece and electrode such as the material's melting temperature, and its electrical and thermal conductivity [11-12]. The electrode used in this study is Cu40W60 is an alloy made on the basis of the powder metallurgy process, 40% Copper (Cu), with a grain size < 150μ and 60% tungsten (W) medium grain size 20 ~ 100μ. by pressing the tungsten particles (W) in the desired shape then we put the powders or copper plates whose pressing W is low or moderate (medium) causing porosity during sintering. Copper infiltrates into tungsten to join the grains the life of the electrode depends on the infiltration of copper into the tungsten and the physical properties such as density especially and the hardness also the chemical properties such as purity, granometry. Sintering was therefore carried out at a temperature of more than 1100°C. The CuW combines the properties of both metals, resulting in a material that is a high thermal conductivity, electrical conductivity, and heat resistance. Recently some investigators have tried to model and optimize the EDM process of different metals and alloys [13–23]. Since CuW is susceptible to wear, holds up very well in sharp corners, the electrode provides more geometrical accuracy than the other electrodes Kern, [24]; Beri et al., [25]. Therefore, the main objective in EDM machining of material is always having higher material removal rate and lower as electrode wear rate in order to improve the productivity save cost it is the main aim in this study.

According to all the studies carried out in the research it has been found that attempts to study the effect of EDM parameters on the surface finish with (Cu-W) electrodes are still rare?

A literature review concluded that the steel potential study of EDM is still under development. The aim of this article is to study the EDM parametric instruments of C100 steel by modifying current and pulses over time. MRR, TWR and SR were considered response parameters. All experiments were performed using a single electrode of each test. The effect of electrode wear rate (EWR) in structural steel is observed.

2. EXPERIMENTAL DETAILS

In the present study, the AISI 1095 steel is selected as work material for experimentation. In experimental tests, themachining of holes of diameter 10mm with depths ranging from 0.1mm to 1mm is performed using the EMD.

2.1 Machine tool

The experiments were carried out under industrial conditions using an EDM ONA NX4 sinking EDM machine, which is shown in Figure 1. It is powered by a 200 A pulse generator. Kerosene oil as the dielectric medium used during the experiments, and the open circuit voltage of 400 VAC is used. The specifications of the machine are mentioned in table 1; the tool is connected to the negative terminal. Three more dominant control parameters of the EDM process namely current (A), pulse (Ton) and pulse-off (Toff) were considered input parameters with MRR, TWR, roughness, hardness, and circularity were been taken as response parameters.

Table 1. EDM machine operating condition

Working conditions	Description
Electrode material	Copper -tungsten
Electrode polarity	negative
Specimen material	C 100
Work table	800 x 600 mm
Work tank	1.200 x 800 x 450 mm
Discharge current	0 – 256 A
Pulse on time	1– 6500 µs
Pulse off time	1– 6500 µs
Dielectric fluids	Kerosene,

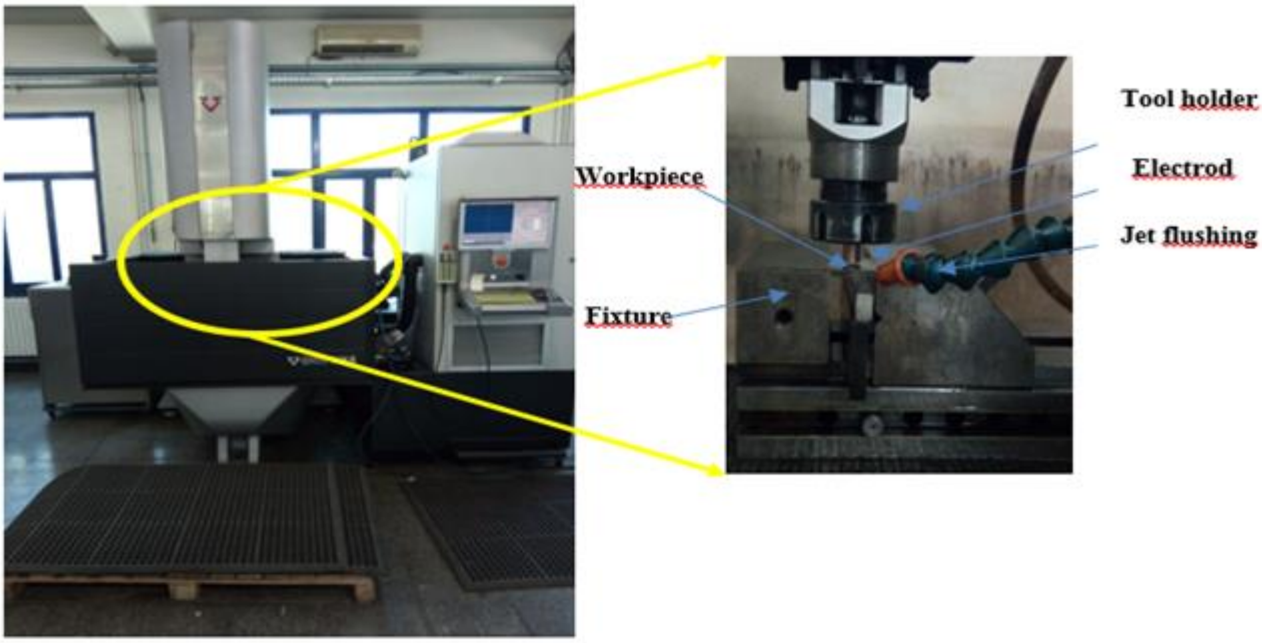

Fig. 1. EDM in operation ONA NX4

2.2 Important performance measures of the process

This section describes some of the important performance metrics of the EMD process. The most widely considered regular performance measures are (i) the material removal rate (MRR), (ii) the electrodewear rate (EWR), and (iii) the surface roughness.

Material Removal Rate (MRR): The average weight of material removed from the workpiece per unit of time during machining is referred to as the material removal rate. This is the most important performance measure as it directly determines the process efficiency of the process. The removal of material is directly related to the energy of the sparks. The higher the spark energy, the higher the material removed from the machined surface, but its turn has many negative effects on the machined surface such as decreased surface quality, dimensional accuracy, and formation of the surface machined layer. Therefore, a stable machining process and optimum parametric adjustment are required to achieve a higher MRR with acceptable tool wear and machined surface quality. It has generally measured in terms of mm^3 / min. Mathematically, it can be expressed as:

$$MRR = 1000 \frac{\Delta w_w}{\rho_w . \mathrm{T}} \qquad (1)$$

Where ΔWw is the weight loss of the working material during machining, ρw is the density of the work material, T is the machining time and MRR is the material removal rate.

Electrode wear ratio (EWR): For precise and cost-effective machining, it is essential to identify and estimate the changes those are taking place within the tool material. The tool material life plays an important role in increasing productivity and subsequently, is an important economic aspect of the process. High wear rate of electrode material leads to interruption during machining which in turn increases machining time and declines productivity of the process by increasing the machining cost. Therefore, a good tool material should have high electrical conductivity to exhibit low tool wear rate. The average weight of the material eroded from tool per unit time during machining is called as tool wear rate (TWR). The process is quite similar to the material removal rate as the tool and work material are considered as a set of electrodes in EDM. It is also measured in terms of mm3/min.

Electrode wear ratio is defined as a ratio of a weight of material removed from tool material per unit time to weight of material removed from workpiece per unit time. It is generally expressed in terms of percent

$$TWR = 1000 \frac{\Delta w_t}{\rho_t . \mathrm{T}} \qquad (2)$$

$$EWR = 100 \frac{TWR}{MRR} \qquad (3)$$

Where ΔWt is the tool weight loss during machining and ρt is the density of tool material.

Surface roughness: In EDM, the fatigue strength of the machined component is highly influenced by the machined surface quality. The surface quality of the machined surface is highly dependent on the energy per spark and dimension of craters. Higher the spark energy, larger is the formation of craters. As a result, the machined surface quality produced becomes poor. Generally, the surface quality of the machined surface is measured with a precision surface roughness tester. It is measured in terms of micrometer.

Further, ROC is determined with the help of the equation given below (refer to Eq. (4)).

$$ROC = (D_w - D_t)/2 \quad (4)$$

where: D_w and D_t represent the diameter of the workpiece (mm) and the tool (mm), respectively.

2.3. Work Piece Material

The working material used in this study is AISI 1095 unalloyed steel, delivered in the normalized state, allows after quenching to obtain an appreciable surface hardness (60 to 65HRC) is specially designed for mold making, tooling, impression plates, punches and dies, the chemical composition of the working material is given in Table 1. The working material dimensions are (45 x 25 x 3.5)mm ± 0.2, density 7.78g/cm^3.

Fig. 2. Works Pieces and Copper-tungsten

Table 2. Chemical composition of AISI 1095 steel

Element	Composition (%)
C	0.95 - 1.05
Mn	0.15 - 0.30
Si	0.15 - 0.30
P	≤ 0.030
S	≤ 0.020
Cr	≤ 0.25
Ni	≤ 0.20
Cu	≤ 0.20

2.4 Description of Electrode Material

There are a variety of materials that can be used as a tool for the EDM process such as copper, brass, silver alloys, copper-graphite alloys, graphite. The electrode used in this experiment is Copper-tungsten Cu40W60. The shape of the electrode is cylindrical with a diameter of (10±0.05)mm was manufactured using a conventional lathe machine.

2.5 Design of Experiments

Once the steel plates are prepared, their machining characteristics are being studied with the EDM process. Various materials can be used as cutting tool materials in the EDM machining process. In the present work, Copper –tungsten electrode is used ascutting tool material to machine steel plates. The experiments are conducted on an EDM machine type ONA NX4 (refer to Figure 1), the polarity of the electrode and workpiece are set as negative and positive respectively. The Kerosene oil as used as the insulating liquid during experimentation. Steel plates with 3.5mm thick are considered as the workpiece material and Copper - tungsten with 10 mm diameter (refer to Figure 2) is used as the electrode material for the experiment. In the present research paper, the open circuit voltage is selected, peak current and pulse on time are chosen as chosen as input process parameters and MRR, TWR, SR and ROC are chosen as responses. Table 3 shows the ranges of input variables decided to conduct the experiments.

Fig. 3. Tool electrodes used for experiments

The weight of the workpiece and the electrode before and after the machining were measured by a Digital balance AP 250 D having the accuracy up to 0.1mg and the surface roughness was evaluated with a portable regosimeter (Mitutoyo - softest -211). The surface roughness of the part can be expressed in different ways, including the arithmetic mean (Ra), the average peak-to-valley height (Rz), or the maximum roughness (RP), and so on. Generally, RS is measured in terms of arithmetic mean (Ra). The arithmetic average or average surface roughness, Ra is considered in this study for the evaluation of roughness. Ra was measured three times on each specimen and the average value was calculated.

Roundness is an important criterion while considering the precision of EDM processing for intricate shapes. It is considered a difference between the radial distances of nearest and farthest point from the geometric center of the hole. To produce the desired fit, EDM process faces a challenge to produce zero out of roundness. Due to the impact of debris coming out of hole along with pressurized dielectric fluid, a hole at the top gets more wear than other surfaces of the hole and thus out of roundness always occur in EDM process [26]. The wear of tool also accounts for irregularities. The roundness was measured by OPTIV Performance 443 Dual Z Coordinate Measuring Machine (CMM) manufactured by HEXAGON METROLOGY SAS [27]. The machine CMM combines optical and tactile measurement in one system. The system supports multi-sensor measurements using the Vision-Sensor, the touch-trigger and scanning probe, the TTL laser (Through-The-Lens) as well as the innovative Chromatic White Light Sensor (CWS). Measurement software is PC-DMIS Vision. Figure 3 shows coordinate measuring machine used for the investigation and the sample results obtained using CMM respectively. For future studies, form parameters of the hole such as cylindricity, ovality, parallelism, and taper can be explored.

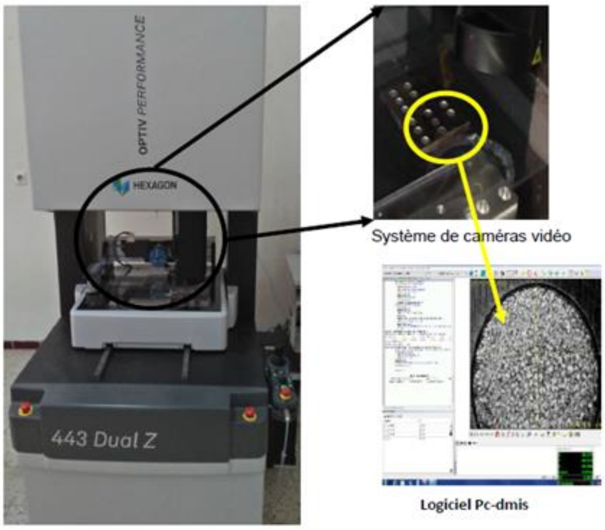

Fig. 4. MMT OPTIV PERFORMANCE 443 Dual Z

2.6 Presentation of Pc • dmis

Pc • dmis is a software that you can find on three-dimensional machines (all brands), measuring arms, laser measurements and now on vision machines. It has been specially adapted to the world of vision:

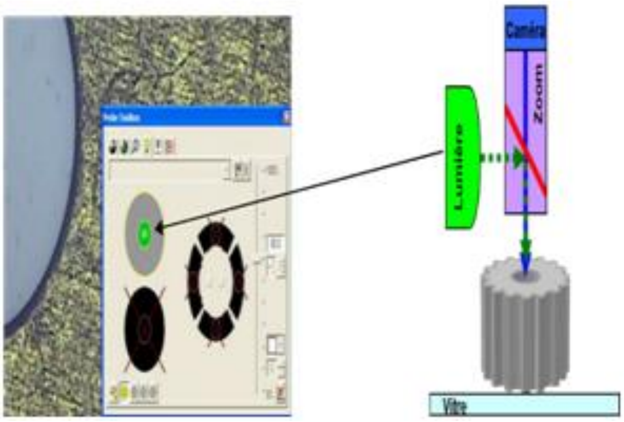

Fig. 5. Episcopic ring: (Ring concentric to the camera)

Simplified measurement tools (We are in 2D) and specific functions added. BUT it's the same software, just by selecting a camera as a measuring element (probe) you access these tools.

3. RESULTS AND DISCUSSION

The machining work using the EDM tool was completed using an L25 orthogonal matrix and the results are shown in Table 3.
A wide range of MRR (0.00125-57.2003) mm^3/min, TWR (-4.29316–4.66164)mm^3/min, SR (0.80-3.83)µm, and Roundness (0.034-0.16)mm were observed with differentcombinations of process parameters. Process on the outcome of the responses is demonstrated in the following subsections.

Table. 3. Experimental results

N°	Ip (Amp)	V (Volt)	T_{on} (µs)	T_{off} (µs)	MRR (mm^3/min)	TWR (mm^3/min)	EWR (%)	Ra (µm)	Roc (mm)	Round (mm)
01	0.2	-200	0.5	6	0.00859503	-0.000400214	4.656339088	0.8	-0.13	0.034
02	0.3	-200	2	6	0.001254093	0.000306176	24.4141371	0.97	-0.09	0.035
03	0.4	-200	2	6	0.012896401	-0.000993483	7.70356599	0.96	-0.05	0.037
04	0.5	-200	3	6	0.066642836	0.020305699	30.46944001	1.74	-0.05	0.041
05	1	-200	3.2	6	0.216307468	-0.18328824	84.73504951	1.72	0.011	0.049
06	2	-200	4	6	0.379119631	-0.026208614	6.913019575	2.07	0.012	0.049
07	12	-80	4	40	0.234912036	0.049588679	21.10946696	1.6	0.047	0.05
08	12	-80	12	40	0.507281004	0.090602122	17.86034196	2.25	-0.01	0.05
09	14	-80	6	40	3.150170713	0.53895253	17.10867693	1.72	0.042	0.053
10	14	-80	12	40	4.167615571	0.276297583	6.629632181	3.34	0.074	0.054
11	24	-80	10	40	7.475020379	1.040213783	13.91586552	2.08	0.054	0.054

12	24	-80	12	40	8.499962893	-2.869527981	33.75930009	3.31	0.065	0.055
13	32	-80	10	40	10.06092798	1.096221346	10.89582738	2.4	0.06	0.056
14	32	-80	20	50	10.9222567	0.765860917	7.011929286	3.83	0.091	0.056
15	32	-80	12	40	11.448173	1.062384799	9.279950597	2.54	0.069	0.057
16	48	-80	12	40	22.93477251	2.392993245	10.43390879	2.44	0.065	0.062
17	48	-80	20	50	27.47376704	-0.832190319	3.02903609	3.41	0.095	0.065
18	48	-80	10	40	27.68122693	-0.289130199	1.044499218	2.6	0.077	0.066
19	64	-80	10	40	28.77130752	3.201338794	11.12684501	2.37	0.068	0.068
20	64	-80	12	50	30.57553957	2.989341283	9.776904432	1.93	0.077	0.068
21	64	-80	20	50	31.45545042	-1.710467637	5.437746446	2.86	0.102	0.076
22	96	-80	12	50	33.87685848	4.018672757	11.8625898	2.3	0.065	0.085
23	96	-80	20	50	40.7924755	-1.3136673	3.220366813	2.44	0.082	0.089
24	128	-80	12	50	49.46883101	4.661642452	9.423393188	2.63	0.077	0.137
25	128	-80	20	50	57.20030158	-4.293159372	7.505483805	2.44	0.112	0.16

The variation of these curves for MRR, TWR, and ROC with respect to the variation of the value of the parameters of the input process is illustrated in Figures 4, 5 and 6, respectively. From these curves, it has been observed that the RRM increases with increasing values of peak current and pulse over time. This can be explained by the fact that the increase of the peak current and the pulse over time results in the availability of more energy to remove the material from the workpiece and the cutting tool. In addition, TWR also showed the effect similar to that of the MRR, it is further observed that TWR has also followed the same trend, but the amount of material removed is very less compared to a room. The ROC plots show an increase in its value with the increase of the peak current and the pulse over time. This may be because increasing these values has resulted in the availability of larger amounts of thermal energy for longer periods. This leads to the removal of non-uniform material along the circumference of the profile. Moreover, it is observed that MRR is directly proportional to the energy of the input pulse. The current increases the discharge energy per pulse also increases and hence large craters are formed. This results in the increase of MRR. The negative value for the lowest TWR indicates that the weight of the electrode after machining is higher than before machining because of the deposition of the carbon and the material of the part, [28-29].

The quality of the surface is a demanding aspect from the point of view of quality. However, the effects of process variables in machining are very valuable for machinability problems. In this article, for the analysis of the surface quality of the machined part, the term R_a is measured and listed in Table 3. Ra is the largest for the higher values of Ip and Ton. The main shape of the Ra effect plot (Fig. 7), Ra increases with increasing Ip for a while, then begins to slightly decrease with an additional increase in Ip as the current increases at a constant voltage. Due to the increase in current and pulse on time, more intense energy is supplied to the gap between the tool and workpiece leading to a powerful explosion which causes craters on the surface of the workpiece and thus surface roughness increases.

Roundness increase with longer pulse rate. Rounding irregularities also occur due to increased wear of the tool.

From Figure 8, it is observed that roundness increase with longer pulse rate. Rounding irregularities also occur due to increased wear of the tool. The MRR is mainly affected by Ton and the current. The MRR increases with increasing current and pulse, resulting in a greater amount of heat energy transferred to the room. At the same time, the roundness of the hole increases due to the erratic sparks generated due to the high current and the pulse value. Thus, increasing the MRR will result in a decrease in the geometric quality of the hole. It can be deduced that as MRR increases, the roundness of the hole also increases. The variation of the roundness is the same as that of the MRR because the increment in all the responses is the result of the increase of the current and the pulse time.

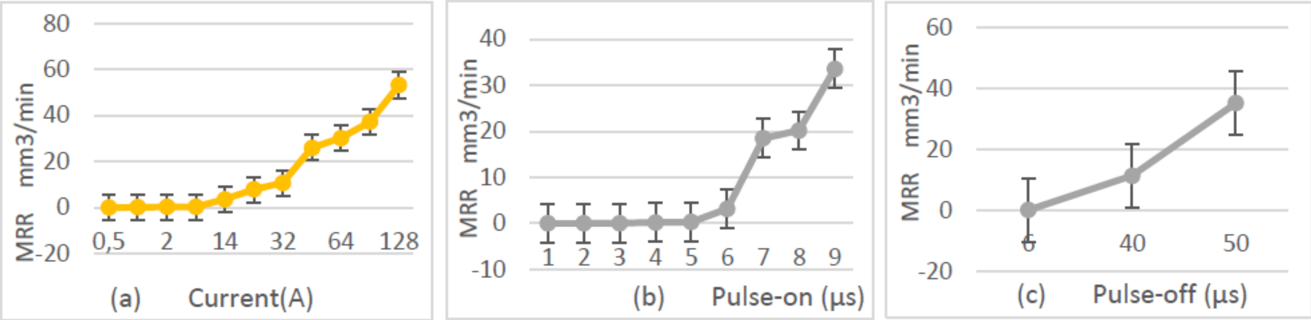

Fig. 6. Plots of MRR curves with: (a) peak current, (b) Pulse-on time, (c) Pulse-off time.

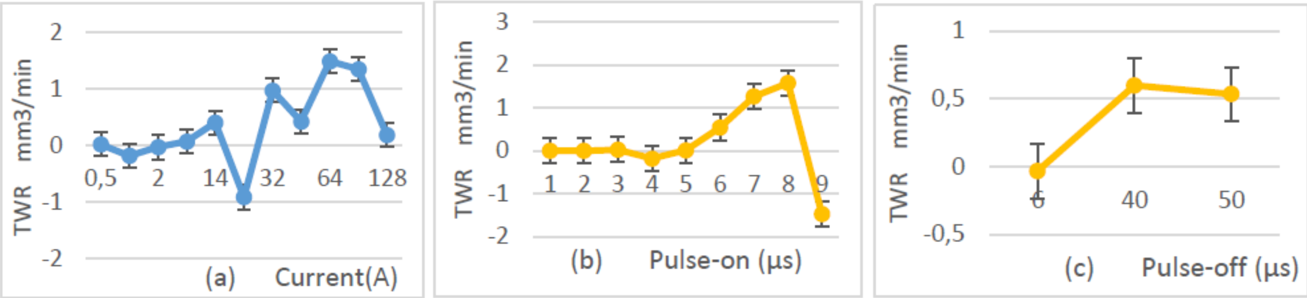

Fig. 7. Plots of TWR curves with (a) peak current, (b) Pulse-on time, (c) Pulse-off time

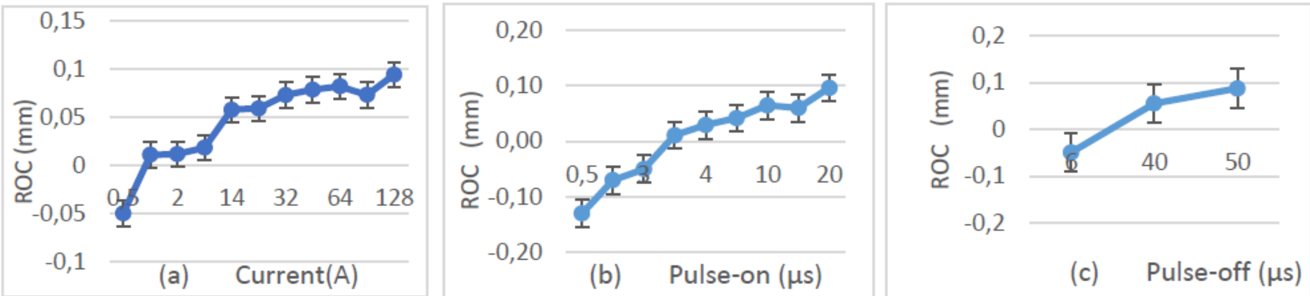

Fig. 8. Plots of ROC curves with (a) peak current, (b) Pulse-on time, (c) Pulse-off time

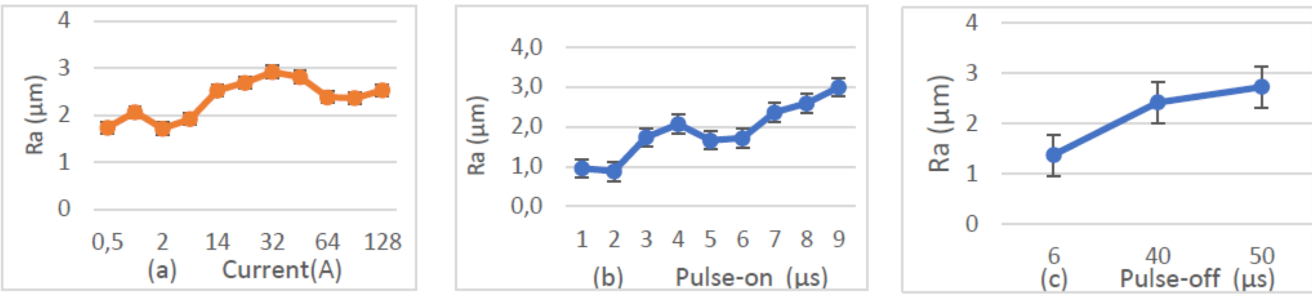

Fig. 9. Plots of Ra curves with (a) peak current, (b) Pulse-on time, (c) Pulse-off time

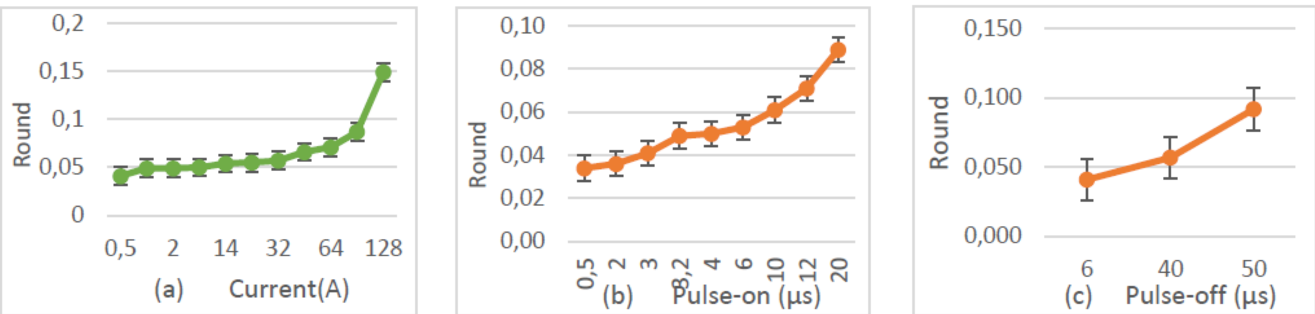

Fig. 10. Plots of Roundess curves with (a) peak current, (b) Pulse-on time, (c) Pulse-off time

4. CONCLUSIONS

This paper discusses the effect of various input parameters on certain performance measures during machining of tool steel in die electrical discharge machine. Gap current, pulse on time, pulse off time, were considered as input process variables. Based on the analysis it was found that gap current, and pulse on time are the significant parameters that affect the material removal rate.

The AISI 1095 is machined on an EDM to drive in a range of electrical process parameters. The variation of current and pulse as a function of time is observed in the output responses of MRR, TWR, SR, and circularity. The main conclusions of this experimental study are as follows. Peak current, pulse off time and pulse on time significantly affects the MRR, TWR, SR, and circularity in EDM.Analysis of variance shows that peak current and Pulse on time are having more influence on material removal rate. Surface roughness was mainly affected by the current and pulse on time. At a higher value of current causes the more surface roughness. The higher surface finish can be achieved value can be achieved at lower current. Peak current and pulse on time are the most influential parameters for reducing surface quality.

The material removal rate is the most important performance measure in this study. In order to improve productivity in EDM machining of AISI 1095, the higher peak current and pulse duration up to 128A and 50µs respectively are used. The conclusion can be made the peak current is the most influential parameter for achieving high MRR while for pulse duration it shows insignificant for improving MRR when EDM of tool steel using Copper tungsten electrode. For electrode wear rate, the longer pulse duration used may improve the EWR but affect adversely when higher peak current used. For surface roughness, lowest peak current and the lowest pulse duration is suggested in order to achieve the good surface finish

Thus, it is possible to machine AISI 1095 by EDM. The experimental results can provide a database for future studies on tool steel machining by EDM.

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